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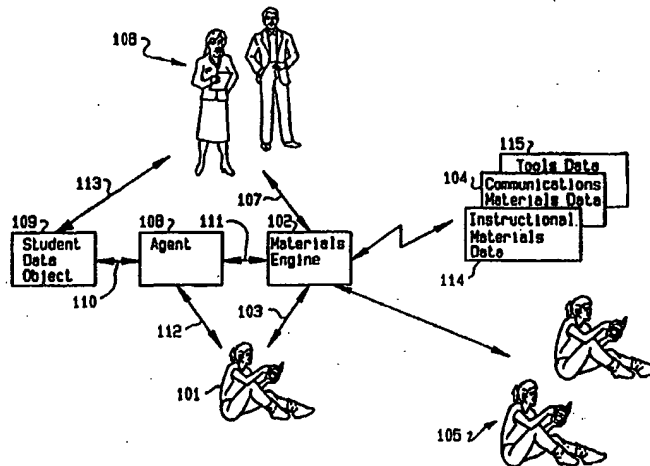
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**(54) Title:** AGENT BASED INSTRUCTION SYSTEM AND METHOD



**(57) Abstract**

This invention relates to a system and method for interactive, adaptive and individualized computer assisted instruction. This invention includes an agent (108) for each student (101) which adapts to its student, and provides individualized guidance to the student and controls to the augmented computer assisted instructional materials. The instructional materials of this invention are augmented to communicate the student's performance and the material's pedagogical characteristics to the agent, and to receive control from the agent. Preferably, the content of the communication between the agent and the materials conforms to specified interface standards so that the agent acts independently of the content of the particular materials. Also preferably, the agent can project using various I/O modalities integrated, engaging, life-like display persona(e) appropriate to the preferences of its student, and appear as a virtual tutor to the student. Finally, preferably this invention is implemented on computers interconnected by a network.

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**AGENT BASED INSTRUCTION  
SYSTEM AND METHOD**

**1. FIELD OF THE INVENTION**

5 This invention relates to a system and method for  
interactive, adaptive, and individualized computer-assisted  
instruction of students, preferably implemented on network  
connected computers. More particularly the system and method  
includes for each student an agent adapted to that student  
10 which monitors its student's instructional behavior, responds  
to teacher direction, and controls the instructional  
progress, and guides its student, all of which constitute one  
aspect of a virtual tutor. Preferably, the viewable on-  
screen aspect of the agent includes customizable multimedia  
15 presentation personae, which constitute a further aspect of a  
virtual tutor.

**2. BACKGROUND OF THE INVENTION**

The application of computers in education has been  
20 limited by several problems, including a failure to provide  
systems that adapt or individualize to each student, a  
failure to integrate systems effectively into the existing  
classroom in elementary and secondary schools, and a failure  
to exploit technological developments. Although during the  
25 last three decades, a number of interactive educational  
techniques have been implemented on computers, all these  
systems lack the ability to recognize and to adapt to each  
student's individual characteristics. The common motivation  
for interactive educational techniques was the recognition  
30 that individual student interaction fosters learning to a  
greater degree than mere passive exposure to a fixed pace  
presentation (Kulik et al., 1986, Effectiveness of computer-  
based adult learning: a meta-analysis, *Journal of educational  
computing research* 2:235-252; Kulik et al., 1983, Effects of  
35 computer-based teaching on secondary school students, *Journal  
of educational psychology* 75:19-26). Existing, interactive  
educational techniques have many variants: programmed

instruction, mastery learning, audio-tutorials, direct instruction, personalized system of instruction, precision teaching, fluency learning and others (Engleman et al., 1982, *Theory of instruction: Principles and Applications*, Irvington, New York; Keller, 1968, "Goodbye, teacher...", *Journal of Applied Behavior Analysis* 1:79-89; Lindsley, 1990, Precision teaching: By teachers for children, *Teaching Exceptional Children* 22:353-359; West et al., 1992, *Designs for Excellence in Education: the Legacy of B.F. Skinner*, Sorris West, Inc., Longmont, Colorado, pp. 147-160). Several systems have attempted to harness the interactivity of the computer for these interactive educational techniques. In early work, for example, text-based programmed instruction was converted to computer format and implemented on time-shared systems. This early development was extended with more sophisticated computer-assisted instruction ("CAI"), also known as compute based training ("CBT").

In CAI, for example, the computer acts as a teaching machine. A program presents instructional displays, accepts student responses, edits and judges those responses, branches on the basis of student responses, gives feedback to the student, and records and stores the student's progress. Examples of CAI systems include those of Carbonell, 1970, AI in CAI, an artificial intelligence approach to computer-assisted instruction, *IEEE Transactions on Man-machine Systems*, 11:190-202; Osin, 1984, CAI on a national scale, *Proc. 4th Jerusalem Conf. on Information Technology*, pp 418-424; Seidel 1971; Koffman et al., 1975, Artificial intelligence and artificial programming in CAI, *Artificial Intelligence* 6:215-234. Effective CAI instructional materials for a limited number of specific topics have been developed, as have special "authoring languages," which assist instructional developers on the tasks of designing instructional materials. U.S. Patent No. 5,310,349 is exemplary of such CAI systems.

However, existing CAI systems do not adapt to their students. These systems merely sequence students through

educational materials, based only on student performance during a current lesson and using only parameters such as recent responses and pre-requisite patterns. These systems do not gather or use information on more comprehensive  
5 student characteristics, such as past student performance, student performance on other courses, student learning styles, and student interests.

A greater deficiency is that existing CAI systems do not recognize characteristics of their individual students. They  
10 cannot be individualized or made responsive to their students styles. Thereby, these system ignore those roles of a human tutor that can be of unparalleled significance in the education of an individual. The human tutor assists in scheduling and prioritizing and in maintaining interest  
15 through proper reinforcement and knowledge of student abilities and preferences. A human tutor observes and addresses patterns of errors and maintains a consistent manner of interaction across a broad range of subject matters and activities. Moreover, a human tutor effectively  
20 integrates the cognitive, personal and social aspects of the instructional situation. In other words the human tutor provides a level of individualization based on student styles and on requirements of the instructional task. Furthermore, the human tutor provides an equally effective interaction  
25 with the teacher by accepting individualized instructions, collecting data and providing detailed reports. By failing to address these higher order services and roles of an effective human tutor, existing CAI systems fail to fully engage their students and thus fail instruct as well as  
30 possible.

Additionally, a further problem of computer assisted instruction, particularly in primary and secondary school settings is poor integration into the rest of the school curriculum and often poor quality of the educational  
35 materials. In application to elementary and secondary schools, two main patterns of instructional computer use prevail, which illustrate the compromises prevalent today.

In one pattern, the integrated learning system ("ILS") is a dedicated installation that is used in schools to teach basic strands of reading, mathematics and related topics, spelling, writing, and other language arts, from grades one to six, or perhaps to eight or nine (EPIE, 1990, *Integrated Instructional Systems: an Evaluation*, Educational Products Information Exchange, Hampton Bays, N.Y.). The paradox with this pattern, regardless of the quality of the instruction offered by these systems, the work of students in ILSs bears little relation to what goes on in the classrooms in that very same topic. The fundamental reason is that the teacher cannot influence or respond meaningfully to variations in student progress or to relations between the CAI curriculum and the classroom text, materials and activities. This is the case even where the ILS installation produces reports in some detail as to each student's progress and standing.

The second pattern of computer use in schools is that of standalone short units on specific topics (TESS, 1996, *Database of Educational Software Systems*, Educational Products Information Exchange, Hampton Bays, N.Y.). These can be hypercard programs, simulations, or games, and are usually separate from the basic classroom curriculum. Though occasionally of excellent quality, the paradox here is that these products are usually chosen for enhancement, possible optional, and do not account for a major component of school related instruction. No records are kept or returned regarding student performance. These programs have not made a major contribution to school instruction.

Finally, computer assisted instruction systems have ignored or underutilized such important developments in computer technology over the past four years as agent-based system, client-server systems, and networking systems. Though now an active field with a wide spectrum of activities from research to commercial applications, application of agent-based systems in educational, instructional, and homework tasks has not been explored. Software systems for intelligent agents have successfully applied in travel

arrangements, email management, meeting scheduling, stock portfolio management, and gathering information from the Internet (Maes, 1994, Agents that reduce work and information overload, *Communications of the ACM* 37:30-40). In all these applications, software agents perform tasks on the user's behalf, receiving only general instructions from their user but then executing detailed tasks with considerable independence and initiative. In client-server systems, these agents can operate in the client, the server, or both.

10 Recently, adaptive and personalized agent based systems have begun to be developed. Systems with adaptive agents, agents which learn from experience, has made gains with new techniques continually identified. Adaptive agents have permitted new commercially viable adaptive systems

15 implemented across networks. In these systems, an agent is a "go-between," mediating relations in a manner whose function is understood with details being left to the agent itself. The agent acts as a "stand-in" for its user, who is thus freed from direct manipulation of the network. In

20 instructional applications, there is an unmet need for an agent who serves two users: the school system and the individual student. This is the well-known role of the teaching assistant/tutor. Maes, 1994, and others have extended the metaphor of agent to that of personal assistant,

25 an agent who learns some important characteristics of its user, and adapts its behavior accordingly. Agents can learn by a mixture of methods: observation, receiving feedback from its user, receiving instructions from the user, and consulting other agents concerning "similar problems." To

30 combine the important properties of competence, trust, and intimacy that a personal assistant should have, an agent should be in touch with relevant data, represent important facts in a reliable manner, and engage with its user in a personal and fundamentally sympathetic -- at times playful --

35 manner. Approaches to the creation of agents with personal characteristics have begun to be explored. In this work, relevant techniques are found in the tradition of film

animators who, through the portrayal of emotions, gave their characters the illusion of life.

Moreover, computer assisted instructional systems have only haphazardly exploited the potential of client-server systems and networking technologies. Client-server architectures have emerged as the principal architecture of distributed computer systems. Client systems, running under sophisticated windowing operating systems, can support advanced object based software applications, including high speed graphics, animation and audio output. Servers can store gigabytes of data and programs at central or distributed locations at quite reasonable cost. Object oriented database systems have been developed to store structured data on servers.

Client systems, in a striking change from only several years ago, now virtually all have multimedia capabilities, including high quality graphics, sound, and at least limited video playback capability. Text-to-speech software is presently available for use with these systems, and speech recognition software is on brink of widespread commercial acceptability on low cost platforms. New authoring tools support graphical methods for generation of multimedia presentations and computer based instructional materials having corresponding sequencing logic.

Clients and servers can be linked remotely with increasing convenience and decreasing cost. The Internet has emerged as a means of providing an inexpensive means of connecting computers to provide effective communications and access to information and other resources such as software. Further Internet developments that made the Internet truly universal include the HTML and the HTTP protocols, which provide platform independent access to hyperlinked multimedia information, and the Java™ programming language, which provides platform independent software for Internet applications programming. Subsets of the Internet -- intranets -- have become an increasingly important means for disseminating information and enabling communication within



constrained domains, such as a single school system or corporate enterprise.

Existing CAI systems have not addressed these functional deficiencies nor have they exploited the possibilities of  
5 existing technologies.

Citation of references hereinabove shall not be construed as an admission that such a reference is prior art to the present invention.

10                   3. SUMMARY OF THE INVENTION

The Agent Based Instruction ("ABI") system of this invention is a system and method for interactive, adaptive, and individualized computer-assisted instruction and homework, preferably implemented on network connected  
15 computers, that overcomes these problems by providing the following objects in preferred and alternative embodiments. This invention provides a more effective system responsive to the needs of several parties interested in education.

An important object of this invention is to provide the  
20 student with a virtual tutor, by having agent software ("agent") adapted to each student that offers a high quality of individualized student interaction and that manages or controls instruction in a manner approximating a real tutor. The agent exercises management or control over the computer-  
25 assisted instruction materials and provides information and help to the student, both synchronously and asynchronously to particular instructional materials. Agent behaviors are sensitive to both the educational context and to the history of student behavior.

30 In a preferred embodiment of this invention the agent integrates data from several sources. From computer-assisted instructional materials, it accepts data on the methods of instruction adopted by particular materials and on student performance in the instruction. From the student, it accepts  
35 direct interactions as well as using the history of previous student performance stored in a student data object. From the teacher, it accepts data on customization and student

assignments. From the school, it accepts data on assigned courses, data on analysis of student body performance, and educational standards and criteria. In a preferred embodiment, these inputs allow individualization of agent  
5 interaction. Alternative embodiments are responsive to additional data types and sources.

In a preferred embodiment of this invention, diverse agent behaviors are handled uniformly by a single means. The diverse behaviors include encouragement and feedback,  
10 providing meta-cognitive help on ongoing instruction, managing or controlling and individualizing computer based instruction to the student's learning modes, and assistance with assignment management. These diverse behaviors are selected from a set of potentially appropriate candidate  
15 behaviors. This set of candidate behaviors is ordered and the highest ranked behaviors are chosen.

In a preferred embodiment of this invention the diverse agent behaviors adapt to the student based on a variety of information about the student. The agent modifies its  
20 behavior on the basis of a growing history of interactions with the student over time, as this history of student performance is stored in the student data object. The agent can also modify its behavior on the basis of teacher and school system supplied information.

25 Another important object of this invention is that the agent presents itself on-screen to the student with integrated, and optionally, animated multimedia persona, or preferably a plurality of persona (hereinafter called "personae"). The on-screen agent can appear as living  
30 entities, which in grade school can be comfortable "Study Buddies™" and in adult training can be appear as an objective "Concept Coach". The on-screen agent instructs, motivates, engages and guides its student.

In a preferred embodiment, the on-screen agent can be  
35 dramatized by a single character or by a cast of interacting characters. The interaction between these actors can be individualized to reflect the pedagogical response of the

agent. To maintain student interest in the agent response, story lines continuing across materials or session can be used.

In a preferred embodiment of this invention the voices, 5 gestures and motions of the personae are derived from the chosen behaviors, student personae preferences, and the history of recent behavior by selection from tables containing a rich variety of alternative sound and visual display objects. All elements of the on-screen agent display 10 are then synthesized in an integrated display script calling for graphics, animation, video, or sound as appropriate. These scripts are then bundled into applets, run-time program fragments that represent a complete element of performance. This display is highly configurable by the student, the 15 teacher, or the system administrator.

It is an advantage of this invention that elements of the display objects can be created by artists, animators, singers, and so forth, as data snips. Pluralities of data snips can be stored in libraries of dynamic clip art and then 20 installed in an implementation of this invention. In this manner the on-screen agent personae have an appropriately contemporary, realistic, and engaging manner. Data snips are, in general, short clips of sound, voice, graphics, animation or video, or combinations of these used to 25 construct the on-screen agent. A data snip can also be a complete preformatted animated sequence, perhaps in the format of a talking animated daily cartoon strip.

Another important object is that the method and system of this invention is adapted to implementation on a variety 30 of networks. When so implemented, the interactive, adaptive, and self-paced computer-assisted instruction and homework provided by this invention is available to geographically dispersed students and from geographically dispersed schools. For example, an implementation of this invention as a 35 "HomeWork Network™" can make computer assisted homework available to students of all levels at home. In addition to computers located at residences of students, the student can

also access homework materials at computers located in youth centers, libraries, schools and other locations.

In a preferred embodiment, the network on which this invention is implemented as an intranet configured of  
5 appropriate links and utilizing the known TCP/IP protocol suite, and as appropriate, ATM technologies, including World Wide Web, associated browsers, and mail format extensions. Implementation over the public Internet is equally preferred in cases where extensive connectivity is needed.

10 A further important object of this invention is to utilize augmented computer-assisted instruction materials which present to students a variety of interactive, adaptive, and self-paced computer-assisted instruction and homework materials in a manner which informs the agent of a student's  
15 progress and performance and which permits the agent to manage or control the materials to the student's pedagogic characteristics. Thereby, the ABI system can effectively guide and engage students in their educational tasks.

In a preferred embodiment, these instructional and  
20 homework materials are composed of materials data presented by a materials engine. The materials data includes display objects containing the substance of the instruction, logic to sequence the display according to student input, and notations. Notations are augmented definitions that serve to  
25 pass information to the agent concerning the materials and the student. For example, notations classify key sections of materials which are educationally significant student actions. Preferably, authoring tools assist in developing these augmented instructional materials. Materials tasks and  
30 sequences are created and entered by instructional designers and subject experts. Notations are usually entered by instructional designers and can be customized by teachers.

In a preferred embodiment, the information passed in the notations is standardized according to an instruction  
35 materials interface standard. This standard establishes a uniform way the materials independent data relating to student performance are to be provided to the agent and a

uniform way for the agent to guide the student in a materials independent manner.

A further important object of this invention is to provide to the student a range of tools which are integrated  
5 with the agent in a manner similar to the instructional materials. These tools include general tools helpful to assigned instructional tasks, and special tools for group work and communication and for student scheduling.

In a preferred embodiment, the general tools include at  
10 least a calculator, an encyclopedia, a dictionary, a thesaurus, each appropriate to the several levels of students, which can access an ABI implementation. In a preferred embodiment, the group work and communication materials allow, when permitted, message exchange, student  
15 linking into groups for joint work, and student linking into groups for structured work such as contests. In a preferred embodiment the student scheduling tool records assigned student activities and their priorities. In an embodiment, this tool can be consulted by the student to view schedules.  
20 It can be consulted by the system to prescriptively schedule required activities, to permit student choice, or to permit a mixed scheduling initiative. Finally, it can be consulted by the agent to offer scheduling advice to the student. Typically, student assignments are set by a teacher.

25 An object of this invention is reporting of student performance to students, teachers, parents, administration, or to other appropriate individuals in a business enterprise or other commercial versions. These reports include the unique data on the student's pedagogic performance  
30 accumulated and analyzed by the agent, as well as all the usual and expected performance data on specific materials available in existing computer-assisted instruction systems. In a preferred embodiment this data is derived from the student data object, where all permanent student data is  
35 stored. These data objects are preferably stored in an object oriented database system against which are run reports of this data. It is an advantage of this invention

in a school context that parents can have access to current data on their children, and thereby play a more informed role in their children's education.

Another object of the invention is to utilize current  
5 technologies for student interaction. When available, this invention is adaptable to Network Computers ("NC"). NCs are low cost computers specifically designed to access intranets or the public Internet. In a current preferred embodiment and implementation, this invention is adaptable to multimedia  
10 PCs for some students, and to such special interaction technologies as can be advantageous to special students or students with special needs. Typical interactive devices include keyboards, mice or other pointing devices, voice recognition, joy-sticks, touch activated devices, light-pens,  
15 and so forth. Other devices, such as virtual reality devices, can be added as they become commercialized.

It is clear to those of skill in the art that by providing interactive, adaptive, and self-paced computer-assisted instruction and homework delivered over widely  
20 available computer networks this invention has immediate application in public, private, and commercial school environment of all levels. Educational research shows that instruction and homework of these characteristics improves students' educational outcomes. Further, in school contexts  
25 this invention advantageously provides immediate access to student performance and pedagogic characteristics to all interested parties, including parents.

#### 4. BRIEF DESCRIPTIONS OF THE DRAWINGS

30 These and other objects, features, and advantages of the invention will become apparent to those of skill in the art in view of the accompanying drawings, detailed description, and appended claims, where:

Fig. 1 illustrates in overview fashion the principal  
35 functional components of and parties in the ABI system;

Figs. 2A and 2B illustrate in overview fashion an implementation of the functional components of Fig. 1;

Fig. 3 illustrates an exemplary student display screen of the implementation of Fig. 2;

Fig. 4 illustrates in more detail exemplary screen interaction between the on-screen agent and the instructional materials of the implementation of Fig. 2;

Fig. 5 illustrates an exemplary interaction of a student with the ABI system implementation of Fig. 2;

Fig. 6 illustrates in more detail the software components and hierarchy in the implementation of Fig. 2;

Fig. 7 illustrates exemplary message flow through the implementation of Fig. 2;

Fig. 8 illustrates agent action processing of Fig. 7 in more detail;

Fig. 9 illustrates agent behavior processing of Fig. 7 in more detail;

Figs. 10A and 10B illustrate the structure of student data object of Fig. 7 in more detail;

Fig. 11 illustrates exemplary processing of the student data object of Fig. 7;

Fig. 12 illustrates an exemplary sequence of student metarequests and agent metaresponses.

## **5. DETAILED DESCRIPTION OF THE INVENTION**

Sec. 5.1 presents a general overview of the Agent Based Instruction system. Sec. 5.2 describes the preferred hardware and operating software configurations. Sec. 5.3 describes details of the instructional interface between the ABI system and its users. Sec. 5.4 describes in a general fashion the software structure of the ABI system with subsequent sections describing each component in a more detailed fashion. Sec. 5.5 describes the instructional materials and the tools in a more detailed fashion and Sec. 5.6 describes the agent in a more detailed fashion. Sec 5.6 includes detailed description of the preferred interface between the agent and the materials in the ABI system.

### 5.1. ABI System Overview

In the following, the systems and methods of this invention are described in the context of a school system, with examples drawn primarily from elementary education.

5 This invention is not so limited. It will be apparent to one of skill in the relevant arts that this invention can be applied at all levels of public and private education, from pre-school through university, and to all forms of commercial or corporate education. In all these contexts, this  
10 invention has particular utility in making education and training available at school, at the office, at home, at schools with geographically dispersed students and to students at geographically dispersed schools, and at other types of locations. Further, it will be apparent that this  
15 invention can be applied in contexts other than education where monitored interactivity and individualization are to be provided, as in child care or weight loss.

The following glossary contains several terms frequently used in the Detailed Description of the invention. It is  
20 presented here as an aid in order to initially introduce important terms that are more fully described and explained in the following sections.

Agent: agent software together with the data it references  
25 executing in an ABI system.

Agent Based Instruction ("ABI") System: the novel instructional system of this invention, preferably comprising an agent for responsive, adaptive and  
30 individualized instruction of students and a network for distribution of instruction, which projects the personae of the virtual tutor.

Agent Software: software modules that generate responsive,  
35 adaptive, and individualized behavior in the ABI system, preferably implemented according to methods from artificial intelligence.



Applet: an executable program fragment advantageously downloaded to a client across the network, in the ABI system applets are particularly used to represent a complete element of on-screen agent actions, or  
5 performance, (e.g., a character scratching its head and saying an utterance) and can reference various data snips of animation, sound, and scripting information.

Authoring Tools: programs used by instructional designers to  
10 develop materials data, such development includes inserting notations.

Cast: a plurality of persona ("personae") representing the on-screen agent.  
15

Character: an individual persona in the cast of the on-screen agent.

Concept Coach: a possible alternative name for a persona in  
20 the cast of an on-screen agent that is suitable for high school and adult students.

Data Snip: an elementary piece of sound, voice, animation, video, or a graphic; data snips can be combined,  
25 preferably by an applet, to represent a complete element of on-screen agent action.

Electronic Learning Friend ("ELF"): a generic name for any persona in the cast of an on-screen agent; also a  
30 possible alternative name for a persona suitable for middle school students.

Instructional Materials: the components of a course of instruction, such components are selected according to  
35 the course and can include prerequisite tests, pre-tests, lessons, and unit tests.

Materials Data: the content of instructional materials.

Materials Engine: software modules that reference  
instructional materials data and tools data to present  
5 the instruction and the tools to the student.

Meta-request: a student request directly to the on-screen  
agent, an exemplary request is 'asking for a hint.'

10 Meta-response: all responses to a student produced by the  
agent software, as distinguished from presentations by  
instructional materials, tools and communications.

Network: the hardware and software connecting student client  
15 computers to school servers in an ABI system; the  
network connections can comprise fiber optic links,  
wired links, or terrestrial or satellite wireless links.

Notations: interface information inserted into materials  
20 data that causes the materials engine to send and  
receive messages from the agent software; preferably  
notations create standardized interface messages between  
the agent and the materials.

25 On-screen Agent: presentation by the agent software on the  
student's display using such media as sound, voice,  
graphics, animation, video, or other multimedia  
modality; this presentation preferably displays one or  
more life-like personae.

30

Persona: a character in the cast of an on-screen agent.

Personae: the collective plural of persona.

35 Student Data Object: data about each student which the agent  
software references in order to provide responsive,  
adaptive, and individualized instruction to that

student; this data is updated during course of each lesson and is advantageously stored as one object, or alternatively a few linked objects, in the ABI system.

- 5 Study Buddies™: a possible alternative name for personae in the cast of an on-screen agent that is suitable for elementary school students.

- 10 Tools Data: the content of tools supporting particular instructional materials; tools can include a dictionary a calculator, or an encyclopedia; and so forth, and tools data are the content of the dictionary, the calculator, or the encyclopedia.

- 15 Utterance: a text or voiced response by on-screen agent.

- Virtual Tutor: the ABI system components acting together to emulate a human tutor; from an individual student's perspective, the Study Buddies™, ELF, or Concept Coach  
20 appears as his or her personal tutor.

- The following sections of the Detailed Description elaborate each of these terms and describe their connection and interaction so that the ABI system presents responsive,  
25 adaptive, and individualized instruction and assumes the form of a virtual tutor.

#### 5.1.1. Functional Components

- In view of these objects and advantages, Fig. 1  
30 illustrates the principal actors and the principal functional components in an ABI System. These include, generally, materials engine 102, agent software 108, and student data object 109, all of which interact with student 101 and with teachers and administrators 106 via a computer network  
35 described below in conjunction with Fig. 2 to create a virtual tutor of student 101. Student 101 is typically one of many students enrolled in a school or similar institution.

Central to the ABI System is the virtual tutor individualized to each student, which formed by the functioning of agent software 108 with student data object 109, which stores characteristics of student 101 and assignments and standards  
5 set by teachers and administrators 106. Other actors not shown in Fig. 1 can be relevant in particular applications, for example, parents in the case of primary and secondary education.

Materials engine 102 presents educational content such  
10 as instructional units, homework assignments, and testing to student 101. The educational content includes instructional materials data 114, communications materials data 104, and tools data 115. instructional materials data 114 include computer based instructional materials similar to those known  
15 in the art but, importantly, augmented with notations for use in this invention. The materials also include various tools 115 appropriate to particular instructional materials, such as a calculator for mathematics, a dictionary for writing, access to on-line reference sources for research, and so  
20 forth. Further, materials can also include communication materials data 104, which define and provide communication with other students 105 for instructional purposes. Such purposes can provide, for example, the tutoring of one student by another more advanced student, joint work of  
25 several students on one instructional materials lesson as permitted, and educational contests, such as spelling bees. Further, this invention is equally adaptable to other forms of materials that function in the framework of Fig. 1, in particular interfacing to the agent software as indicated by  
30 arrow 111, and that are useful in a particular application of this invention. For example, materials appropriate for child care contexts can differ from the above three classes by, perhaps, having different paradigms of interactivity.

The structure and course of interactions 103 between the  
35 student and the materials is preferably governed by paradigms of educational psychology and sound educational practice, such as are described in the exemplary reference Englemann et

al., 1982, Theory of instruction: principles and applications, New York: Irvington Publisher. At the most immediate level, for example, during homework or instruction, student 101 can make requests and receives responses from materials engine 102 and, in turn, materials engine 102 can make requests and receive responses from student 101. The materials engine can adjust its sequence of presentation in response to student responses. At a next level, the requests and responses exchanged between the student and the materials engine can follow several patterns known in the arts of computer based instruction and which, for example, include the following. First, the student can respond to questions presented by the materials engine, and in the course of responding, can ask for advice or hints, the use of a tool such as a calculator, or other relevant assistance. Second, the student can advance to the next item, lesson, or unit upon successful completion of the present item, lesson, or unit. Third, in case of error, the student can request, or automatically be presented with, appropriate repeat, review, or remediation materials. Finally, at a higher level these patterns of interactions can be analyzed to provide more adaptive responses from the system.

Teachers and administrators 106 also interact with materials engine 102 for several purposes, as represented by arrow 107. For example, teachers can customize existing materials by adding additional items, modifying existing items, altering the order of item presentation, changing the notations (see *infra.*) governing agent interaction, and so forth. A teacher can create particular instances of materials suitable for one class, a group, or even one student. Further, although reporting of student progress preferably occurs by other means, in alternative embodiments the materials engine can directly report student progress to teachers and administrators. For example, this can be done by entering notations that generate messages for the teachers.

Also, instructional designers can create, or "author," materials for use in this invention. Such materials can be original or can be derived from existing textbooks, workbooks or media material. They can employ standardized curricula, 5 pretests such as criterion tests, post-tests, and standardized texts. Authoring instructional materials in a course suitable for interactive instruction typically comprises several steps, including decisions about the objects to display to the student, the sequencing of these 10 objects, and the interactions with the agent. The first step is the selection of objects which carry the education content for presentation to a student. Objects can include visual display items, such as text, graphics, animation or movies, audible display items, such as voice, audio and so forth. 15 They can include input items known in the computer arts, such as buttons to select, selections to chose from, text to enter, hypertext and hypermedia links, functions to perform with student input, and so forth. The second step is the selection of the sequencing logic for the ordered display of 20 the objects to the student and the educationally appropriate reaction to student requests and responses. The sequencing logic can reference instructional controls set by agent software 108, such as a command to increase example density, and preferably is chosen in light of principles of 25 educational psychology and practice as detailed above. The third step is the specification of interactions with a student's agent or virtual tutor, a key component of the ABI system. This specification is made by augmenting the sequencing logic with "notations," which are referenced, 30 called, or executed by the sequencing logic during object presentation and that communicate with the agent, in a preferred embodiment by exchanging messages. In the ABI system, the agent builds an adaptive model of its student's pedagogic characteristics, in other words the student's 35 cognitive styles, by monitoring the course of the student's interactive instruction. The notations are the means for this monitoring. Finally, in order to make materials

available, the authored materials are indexed and stored in the files of the ABI system, preferably on materials server systems.

ABI authoring tools differ from authoring conventional instructional materials in that notations are present in these materials to enable the agent software to update the student data object, to monitor and modify the instruction, student's use of a tool, or a communication task. ABI authoring tools support and facilitate the conversion of existing materials to the ABI instructional format.

As indicated above, an agent unique to each student 101 is important in the ABI system. A student's agent is comprised of agent software 108 in conjunction with a student data object 109 unique to each student. As the agent software monitors its student's instruction, it builds an adaptive model of its student in student data object 109. Guided by this model, agent software 108 acts, first, to manage or control the student's instruction, and second, to directly guide the student in order that the total ABI system can present education to each student in an optimal fashion best adapted to the student's evolving abilities, skills, and preferences. In other words, the agent becomes a virtual tutor by acting as a student's personal and individualized tutor. First, the agent manages or controls instruction of student 101 by directly controlling materials engine 102 in its presentation of materials data 104, 114, and 115 through interaction with the materials engine, as represented by arrow 111. The agent preferably manages or controls the materials engine in two manners, synchronous with materials data presentation, such as when the materials engine encounters an appropriate notation in the data, makes an agent request, and waits for an agent response, and asynchronous with the presentation, such as when the agent software adjusts control parameters which the materials engine references at decision points. Examples of synchronous control are an instructional material asking the agent for permission to allow the student to use a tool, to

receive a hint, or to be given remediation, or a communications material asking the agent for permission to permit the student to engage in a particular type of communication with certain other students. An example of  
5 asynchronous control is the agent setting of pedagogic parameters, such as coaching parameters that the materials engine uses to adjust its presentation, according to the pedagogic characteristics of the student. Exemplary coaching parameters include the time pacing of exercises, the new  
10 concept seeding rate and the density of examples. In this manner, the materials can present interactive instruction according to optimal values of the pedagogic characteristics or cognitive styles of each student as determined from the agent's observation of its student.

15 Second, agent software 108 directly guides the student by exchanging communication with the student, as represented by arrow 112. Student communication also preferably occurs in two manners, synchronously, in which the student directly makes meta-requests of the agent tutor and receives meta-  
20 responses and second, asynchronously, in which the agent tutor itself generates a meta-response in response to some instructional event. Herein, requests and responses are prefixed with "meta" when they are exchanged directly with the agent. Meta-requests include student questions to the  
25 agent - for example: How am I doing? What should I do next? Could you say that another way? - or student requests - for example: I need a hint; I need help. The agent responds to each student question or request. Agent meta-responses can be generated, for example, when the student takes too long to  
30 complete an exercise, when the student makes a series of repeated errors, or when the student achieves good performance. Agent meta-responses can be drawn from such categories as reminders, encouragements, reinforcements, paraphrases, jokes, progress summaries, and so forth.

35 Communication with the agent, represented by arrow 112, include direct student meta-requests that generate agent meta-responses. Other communications derive from



instructional event messages generated and communicated by augmented notations in materials 104, 114, and 115. An event received by the agent can generate no meta-response at all or alternatively can generate an asynchronous type agent meta-  
5 response. At educationally significant points, as the materials sequencing logic presents display objects to the student and receives inputs from the student, the materials data author places one or more notations. When these notation are referenced, called, or executed, important  
10 variables and parameters educationally relevant at this significant point are gathered into a message, along with an indication of the type of the educational event. These messages are events which are then sent to the agent. For example, an educationally significant point is the beginning  
15 of a new instructional sequence. The corresponding event message can include an indication of the topic to be covered, the expected level of difficulty, the expected time to complete, and the educational paradigm adopted. Another educationally significant point is the receipt of a wrong  
20 answer. In response, the materials can generate several messages: a first message can include the time required to make the answer, an indication of the type of error, and an indication of whether the answer is completely wrong or only a near miss; a second message can include text parameters  
25 ("say-it" type message) if the agent chooses to make a specific text or spoken comment about the error; finally, a third message can include the screen location best representing the error ("point-it" type message) to use if the on-screen agent chooses to point to the error or move to  
30 the location of the error. Another educationally significant point can be a long delay in receiving the next student input, at which point the materials engine can send an asynchronous message indicating the time elapsed. Tools data 115 generate events similar to messages from instructional  
35 materials. Communications materials 104 can generate events recording a communication request or an initiation of communication with certain other students for a certain task.

In the case of shared work on one materials, communications materials can generate events recording how this student in progressing with the shared materials; in the case of a contest such as a spelling bee, events recording how this student is progressing in the contest with respect to other contestants.

In addition, in a preferred embodiment agent software also receives messages describing the progress of the student through specific instructional materials. For example, in the case of mathematics materials, such messages can include information that the student is making errors in problems requiring finding common denominators. These event message should preferably all information that can be of interest to teachers and administrators for tracking student progress and tracking course adequacy.

It is important that communication between the student and the agent be engaging. Agent communication preferably utilizes all the modalities of input and output available in a particular implementation of this invention, including text, audio displays such as voice and sound, and video displays such as graphics, animation, and realistic movie clips. For example, in the case of a communication triggered by good performance, the agent can select the display of sound and video clips, from a data snips library, that the student finds pleasing. The agent can further make reward graphics available on the student's screen for a period of time. On the other hand, in the case of error the agent can point to the screen location of the error.

Further, it is highly preferable that the on-screen agent can assume various display personae during student communication. Herein, persona means the effect conveyed to the student of the combined and coherent presentation of multiple display modalities to emulate a particular, apparently living, personality. For example, in the case of elementary education, this can be the selection of tone and animation to emulate a pleasant animal or a known cartoon character. In some cases, characteristics of the display

persona can be selectable by the student according to the student's preferences. In other cases, the personae can be specified by the instructional materials, the teacher or the administrator overriding student persona preferences.

- 5 Personae for an elementary school student can be selected from well-known cartoon characters and can perhaps be called "Study Buddies™." Persona for commercial or corporate education can be adapted to the organizational ethos and can perhaps be called a "Concept Coach." Presentations for  
10 intermediate levels can be called an Electronic Learning Friend ("ELF"). Even though the ABI system through its network, software and database acts as the student's virtual tutor, from the elementary school students point of view, the "Study Buddies™" are his/her personal tutor. Realism in  
15 voice, gestures and movement reinforce this relationship.

Agent software 108 in the ABI system builds an adapting pedagogic or cognitive model of its student in student data object 109 that is independent of the specific materials. Event messages to the agent software from the materials  
20 engine preferably include the information from which this model is built. In general, event messages must include such content as is necessary to describe and parametrize the pedagogic or cognitive style models adopted by the materials in an implementation of the ABI system.

- 25 In an preferred embodiment, the student data object 109 collects all the permanent data about the student maintained by the ABI system. The data objects for all the students are collected for permanent storage in a database system. Preferably, this is an object oriented database, although  
30 this data can be advantageously stored in standard relational databases. In an alternative embodiment, however, the various subtypes of student data in the student data object can be separated into separate objects and stored in separate databases. In particular, it is possible to store the  
35 materials specific progress data separately from the materials independent global student data. Preferably, the student data object is stored as one structured object.

Alternatively it can be stored as a plurality of objects, each object of the plurality perhaps storing only one subtype of data.

The student data objects are accessed not only by the agent software 108, but also by teachers and administrators 106. As depicted by arrow 110, the data object is referenced by the agent in order to generate its actions and is updated by the agent as it processes events and student meta-requests. As depicted by arrow 113, the data object is referenced by teachers and administrators in order to track the student progress and to generate reports concerning the students and materials in the ABI system. Teachers also update the data object to enter schedule information for the student's assignments. Administrators update the object in order to enter the courses and materials the student must master and specify standards and criteria the student must meet.

#### 5.1.2. Exemplary Implementing Structure

Figs. 2A and 2B illustrate an exemplary preferred structure implementing the principal conceptual and functional components of the ABI system as illustrated in Fig. 1. A preferred implementation of this invention is based on a plurality of computers interconnected by a network. Preferably, although all system functions can be performed on all interconnected computers, certain computers are specialized for certain functions, such as student client systems for providing student access or system servers for storing system software resources. Therefore, an exemplary preferred ABI system includes one or more student client systems 201, at which student 202 receives instructional presentations including homework. Other student clients are generally indicated at 203 and can be located at school, at home, or at the office. The system further includes one or more servers 204, at which teachers and administrators 205 gain access to the system. Alternatively, they can access the ABI system at their own client computer systems.

These components are interconnected by a network which consists of transmission medium 206 and local attachments 207. Although the network illustrated in Fig. 2A is of a bus-type configuration, as in a local area network perhaps using collision detection or token passing protocols or both, this invention is adaptable to all forms of networks which support adequate transmission protocols, such as those that are functionally similar to the TCP/IP protocol suite, and as appropriate, ATM technology. Thus, the invention is adaptable to networks constructed from switched or non-switched links to a central server, which can be configured of several LAN attached server systems, to networks including CATV cable or optical links, to networks including radio links either terrestrial or satellite, and to public or private packet switching networks.

A preferred public packet switching network to which this invention is adaptable is the Internet. ABI system nodes can be linked to the Internet in any convenient manner known to those skilled in the art and can include security boundaries (known as firewalls) to prevent unauthorized access. Alternatively, an ABI system implementation can be an "intranet," that is a network constructed according to TCP/IP protocols but using private links of the types enumerated above, and as appropriate, ATM technologies.

In more detail, student client system 201 includes memory 208, which is RAM type real memory or a virtual memory based on RAM type memory and a backing store. Preferably, to reduce size and cost, the client system has no permanent disk storage. When available, a preferable student client can be a low cost network computer ("NC"). A NC is a computer with processor, RAM, and network interfaces sufficient to access intranets or the Internet. A NC is preferable in cases when high-bandwidth network access is available. In cases of low-bandwidth network access, the client system can have one or more disc drives 209 which can be used as a pre-fetch buffer or a read-only cache. The disks preferably are magnetic, although in a less preferable embodiment they can also

include CDROMs. This optional capability serves to enhance communications efficiency in cases where the network has relatively low bandwidth. Large files can be downloaded in advance of a student session or the student client can cache  
5 read-only data across sessions obviating the need for downloading such files. Such caching requires the operating system components to maintain some form of version control of the read-only data. In any case, the student data object, which contains all permanent and read-write student data, is  
10 stored between sessions on a server. This permits a student to access the ABI system services from any available client system at any time by simply downloading the student data object to that client system.

The student interacts with a client system using any  
15 appropriate interactive input/output ("I/O") modes 210. For input, standard devices include pointing devices, such as mouse 211 or a trackball, age appropriate keyboards, optionally speech recognition, and so forth. Speech recognition will permit brief conversations with the "Study  
20 Buddies™," or other personae, in limited areas. The invention is adaptable to special input devices appropriate for particular groups, such as the handicapped, and to devices yet to be constructed. Virtual reality ("VR") interface devices such as VR gloves and VR display helmets  
25 can have immediate applications for special needs students. For output, preferable devices include computer display 212, for displaying objects such as text, graphics, animation, and video, and audio output devices for voice and sound clips. The audio and voice can be constructed from data snips stored  
30 as digitized sound files in libraries. Alternatively, voice can be synthesized from text. The invention is also adaptable to special output devices for special classes of students, e.g. the handicapped, and to new devices being developed.

35 Fig. 2A also shows an exemplary screen layout for a student client that exemplifies the principal functions of this invention. The screen is preferably partitioned so that

principal components of this invention are displayed; and important student actions are represented by icons or buttons. Thus, the screen includes materials and tools area 220 to the left, agent area 215 to the right, and a system toolbar 218, which includes a student customization area 221 at the top. The size of the screen partitions illustrated preferably change from time to time in response to student customization or display requirements. In particular, either the materials area or the agent area can enlarge, perhaps up to the entire screen as needed. Materials area 220 is for the instructional materials, tools, and communication materials to present visual display objects and for these components to receive interactive input. This area is further subdivided into display region 213 and a materials specific toolbar 214. On-screen agent area 215 is for the on-screen agent to receive meta-requests and to display synchronous and asynchronous meta-responses. Also illustrated is an exemplary on-screen agent consisting of a single persona 216 and a meta-request icon 217. The persona can move to other screen areas as required. Both these components are illustrated as appropriate for elementary education. Other visual appearances would be appropriate in other situations. The system area at top includes toolbar 218 for selecting particular available system components. In particular, always available on this toolbar are selection icons 219 for the calendar and scheduling tool. Part 221 of the system area can be reserved for student customization, for example for the display of reward graphics "given" to the student by the agent or virtual tutor.

Functionally illustrated in Fig. 2A is an exemplary memory organization of a student client system when a session is in progress with materials being presented. Layer 222 comprises operating software and network communications. This software provides, among other services, support for I/O devices attached to the client, a file system with cache control, lower level network protocols, such as TCP/IP and ATM, and higher-level network protocols, such as HTTP V2.0.

Basic shared ABI system capabilities are provided by executive software 223. The executive software verifies student identity and access authority, establishes communications sessions with the system servers as required  
5 during client start-up, downloads from the student object database the student data object corresponding to the student in session at this client system, downloads instructional materials scheduled for this student, and download executable software required from the systems servers as-needed. The  
10 instructional material and the software are read-only and are not changed. The student model is updated by the agent during the student session and modified parts are uploaded to the student database on a server for storage. Such downloading can utilize higher level network transfer  
15 protocols, or alternatively, directly use lower level network protocols.

Agent software 225, certain parts of student data object 226, and certain instructional materials software 224 have already been downloaded. The materials are displaying  
20 objects in screen area 220, forwarding events to the agent and receiving agent management or controls, as indicated by arrow 227. The agent is displaying its persona(e) in screen area 215, interacting with the materials, as represented by arrow 227, and is referencing and updating data in student  
25 data model 226, as represented by arrow 228.

Finally, the student client system further includes standard components not shown, such as a microprocessor and input/output interfaces. Alternative implementations of the student client system are within the scope of this invention.  
30 In particular, student client system function can reside on a server system. Further, the client system can be implemented as two machines, wherein a first machine performs substantially all the computations and a second machine is for student interaction and sends student input and receives  
35 display instructions from the first machine.

The ABI system further includes one or more server systems 204 of Fig. 2B with sufficient large capacity discs



230 for storing all student data objects in the student database, all instructional materials, and all software used in the system. The network is used to distribute the software, student data objects and instructional materials  
5 form the servers. In alternative embodiments, there can be more than one server with software and data component storage divided as convenient across the servers. In a further and less preferred embodiment, the server can be a central host system. In comparison to the client systems, servers  
10 preferably have increased performance and higher speed network connections 231 in order to make this stored data quickly available to the one or more student client systems. Access to the body of student data allows teachers and administrators to track student performance by class, grade,  
15 subject, school and so forth. This statistical data is also input into agent processing.

The server systems are preferably configured as shown in Fig. 2B and are loaded with software 232 providing the following function. First, there is operating system,  
20 network services, and file server layer 233. In addition to the functions of layer 222 in the client system, layer 233 also provides a file server facility including file backup and version control. System manger 234 includes facilities for access control, authenticating student access requests  
25 and limiting file access to authorized users. For example, students can be limited to only their personal files; parents to their children's files and curricular related data; teachers to files and student data objects for their classes; while certain administrators have unlimited access. The  
30 system manager can also maintain any necessary system logs. Student data object database 235 is explicitly illustrated. Student data objects reside on the server systems when the associated student is not in session. These objects contain the data which is the source of all teacher and administrator  
35 reports, data by which these staffs schedule student courses and assignments, and data representing the pedagogic model of the student used by the agent software. Instructional

materials databases 240 and directories of executable software also reside on the server systems. When group communications is in use, agents and communication tasks monitoring the groups can reside on the servers. The servers  
5 also contain areas 237 for administrative data and for reports and report software of interest to the administrative staff. Finally, the servers contain teacher areas 238 for data and report software of interest to teachers.

Further, certain instructional materials can be made  
10 available specifically for the teaching staff, along with an individualized teacher agent acting as a virtual tutor for the teachers. The facilities of the ABI system can be used to simplify teacher familiarization and system training. For example, such teacher training can be user instruction in the  
15 ABI system itself, or can be teacher versions of student materials designed to assist the teacher in his/her use and customization (in the nature of today's teacher versions of textbooks). Further, there can be teacher specific tools, for example, to assist in generating student reports and  
20 class management. In this case the server system contains special instructional materials and associated teacher data objects 236 for performing this instruction. Client systems for teacher access have agents unique to individual teachers.

Alternatively, the flexible server structure of the  
25 system permits administrative and teaching staff to perform their specific tasks on any computer system with enough computing resources to support these tasks. As for student access, necessary system components are downloaded from servers to these temporary client systems. Thereby, these  
30 personnel are not limited to sessions on server systems. Further, materials authoring can be done on server systems, client systems, or on separate systems not interconnected with a given ABI system. To make authored materials available, they are transferred to and indexed in the  
35 appropriate server system databases.

Alternative implementations of the functions described for the student client systems and the server systems are

also within the scope of this invention. For example, it is known to those of skill in the art that by the use of various technologies, such as remote procedure calls or messaging, the functions pictured here as grouped together and on one system can be divided and distributed if needed.

## 5.2. System Hardware and Operating Software

The system elements illustrated in Figs. 2A and 2B can be constructed on standard hardware platforms meeting the requirements discussed in this section.

### 5.2.1. The ABI System Network

The utilization of a network is central to the ABI system. It is important that students or teachers be able to access the ABI system from any adequate client system anywhere at the school, at home, and when away from home, as in distance learning. Networks permit students and teachers to participate at more than one school, and, further, permit delivery of homework and instruction to remote locations. In each case the client system must access student data objects, instructional materials, and ABI software from the network.

Access to all system components is typically provided from ABI system servers attached to the network. It is preferable, to use a single large network server in place of several smaller network servers. In all cases, it is preferable to store the updatable student model objects on server systems, in order that they can be downloaded to whatever client system a student accesses. It is also preferable to provide read-only software and read-only instructional materials from server systems. The advantages over local storage of these elements at client systems include simplification of version control and of access control. The student is freed from insuring the client system accessed has all the necessary software and manually transferring if not. Also server storage provides greatly reduced client system storage requirements, in view of the large amount of software and instructional materials in ABI

systems. However, in systems with limited communication bandwidth, it can be preferable to cache recently used software and instructional materials in order to shorten response times.

- 5        Networks suitable for an ABI system can be of any configuration and protocol that meets the system's client-server communication and object transfer requirements, where the client is either a PC or a network computer ("NC"). Suitable networks can be private or public. The preferred
- 10 ABI network in the case of PC clients, according to current technologies, is an intranet running the TCP/IP protocol suite and utilizing ATM technologies as appropriate. In one implementation, utilizing a single large server, such a server can be directly connected to the intranet or Internet.
- 15 In another implementation, utilizing several smaller servers, these servers can be connected into a cluster by a LAN, preferably an Ethernet LAN. In this case, the ABI network is built from a local Ethernet LAN with remote connections to telephone lines using 28.8 Kbps modems, or other network
- 20 links. In an alternate implementation, the network can be visible to the public Internet if adequate security systems (firewalls) prevent unauthorized access. This can make wider access available at lower cost than by switched telephone remote connections.
- 25        The ABI LAN can be further connected to other ABI LAN's and to other networks, such as the Internet, by standard use of routers and gateways. An exemplary protocol for an ABI System network is TCP/IP supplemented with a client-server protocol such as HTTP and object transfer protocol, such as a
- 30 multi-format mail protocol. ATM technologies are used as appropriate. Remote clients are expected to be indirectly connected to the ABI network. These connections can consist of routing over a public network or direct dial-in connections. These connections can be of either low-speed or
- 35 high speed. The ABI system can be implemented on networks such as @Home (Mountain View, CA), which use a combination of ATM, cable modems, TCP/IP and other technologies. The ABI

system can also be hierarchically configured on new network topologies for distance learning in areas with limited communications infrastructure. Primary central servers with ABI software and instructional materials communicate with  
5 remote secondary servers over broadband satellite communication systems. Student clients connect to the local secondary servers through wired or wireless means.

#### 5.2.2. The Client System

10 Considerations governing the choice of client hardware and operation software are described next and are followed by a preferred client node system according to today's technology. These consideration depend on the content of an ABI system and the facilities of technology. As the content  
15 of a system changes and as technology evolves these consideration dictate that the preferred system will change.

The client hardware consists of client input/output ("I/O"), client CPU and memory, and client network access. Turning to the client I/O requirement, standard input devices  
20 such as keyboard and mouse, or other pointing device, are preferable. Color graphics output capability adequate to support partial screen animations is preferred. Sound generation and output are preferable on ABI client systems. Text-to-speech conversion can be done either in software or  
25 in hardware. When economically available, full video capability, for example by providing video decompression hardware such as MPEG decoders, and speech recognition, for example with hardware assists, are also preferable.

The ABI system is also adaptable to special I/O devices  
30 appropriate to special student groups, such as the very young or the handicapped. These include, for example, simplified keyboards, touch panels, VR devices, and so forth.

Client memory must be sufficient to contain resident operating system components, resident ABI executive software,  
35 and dynamically loaded segments of the student data object, instructional materials, and code. High performance CPU's

together with high performance graphics hardware and memory is preferable to enable more advanced presentation effects.

In embodiments where part or all of the ABI software is implemented in special languages, hardware or software  
5 assists for these language are preferable. For example, where such a special language is JAVA™ (Sun Microsystems, Mountain View, CA), JAVA™ chips, which enhance performance of the JAVA™ interpreter, are preferable. The ABI client node in certain embodiments can be a JAVA™ enhanced network  
10 appliance adapted to Internet communication access and the HTTP V2.0, or equivalent client-server protocol.

It is preferable to eliminate the need for permanent data storage devices, such as hard disc drives, by downloading all client software for each session. This  
15 allows the use of low cost 'network appliances' as student client computers. However, for those clients with lower speed network access asynchronous downloading can be used. Storage devices such as hard drives can be preferable for prefetching or caching of read-only software components in  
20 order to reduce start up time. To download 4 megabytes of software using, for example, a 28.8 Kbps modem takes over 20 minutes. In the case of caching on student client, standard version control methods known in the art are necessary to ensure that only up-to-date software and materials data are  
25 used. If an element is found to be out-of-date by querying a server, the current version is downloaded. The student data object is not be cached between sessions since it can be accessed from other client systems.

Client communication hardware can be adapted for either  
30 local or remote attachment. Local access requires network access hardware; remote access requires a communication capability. This invention is adaptable to lower speed access over switched telephone line services, preferably using 28.8 Kbps modems or ISDN interfaces (64 or 128 Kbps).  
35 These bandwidths are adequate for sessions with materials using only voice and limited animations. Prefetching and caching can be required to make fullest use of other

materials at this bandwidth. This invention is also adaptable to high speed access over any available high speed links, such as T1 (1.5 Mbps), T3, ADSL telephone lines, or cable modems (several Mbps), or other means of high speed  
5 access. These bandwidths permit full access to materials without limitation. If economically available, high speed access is preferred. With greater communications bandwidth, the on-screen agent can appear more life-like.

Standard client software includes an operating system  
10 and communication software. The operating system preferably has interfaces to client I/O devices including communications capability and network access, such as a TCP/IP stack. ATM interfaces are present if necessary. Preferably, it also has means for establishing sessions with servers, for providing  
15 file server services, and means for security as specified shortly.

The implementation language or languages of this invention preferably have several features related to the implementability, maintainability, and extensibility of ABI.  
20 The implementation language preferably provides a degree of modularity similar to that provided by object-oriented programming languages. It preferably provides means of dynamically loading across a network and executing additional software segments during program execution. It preferably  
25 provides means of accessing all input devices and of controlling the output devices in a high level display object fashion. It preferably provides a threaded or multiprocessing capability. Less preferably, this invention can be implemented in any computer language, including  
30 assembly language.

In view of these needs and in view of the current technology, a currently preferred client system is a IBM type PC with a Pentium™ 120 Mhz processor, 16 MB memory, a 1 GB disk drive, a Soundblaster compatible sound card with  
35 speakers, a medium performance graphics card such as a Diamond Stealth card with 2 MB of graphics memory, an Ethernet card or a communication card and a 28.8 Kbps modem,

and standard keyboard and pointing device such as mouse. The operating system is Windows™ 95 with network services provided by a World Wide Web browser equivalent to Netscape 2.0 or better and capable of running Java™ applets. Java™ together with standard system and graphics classes is the implementation language.

### 5.2.3. The Server System

The primary function of the server systems of this invention is to store databases of executable software elements, of student data objects, and of instructional materials. The latter two consist of heterogeneous and structured elements. These elements can be stored in a relational database such as supplied by the Oracle Corp. or the Sybase Corp.; they can be stored as specialized data files; or they can be stored in an object-oriented database system such as ObjectStore (Object Design Inc., Burlington, MA). The operating system of the server nodes must support whatever database systems are selected as well as network and application server software to access the databases. Application database server software of this invention preferably provides database access and version control and downloads database elements on client request.

The preferred server hardware and software can vary widely depending on the number of clients to be simultaneously served. This number can vary from 20 at one school to more than 5000 across an entire school system. The number of servers and database distribution across a server cluster can be adjusted by means known in the art to satisfy projected peak loads. A suitable medium performance server system can be configured on a high end INTEL Pentium or DEC Alpha system with adequate memory and disk space. Windows™ NT is an adequate server operating system, and Internet server software similar to that from Netscape is adequate for network access. The preferred database is an object oriented database such as ObjectStore. In this embodiment, application database access uses a common gateway interface



("CGI") program also providing database access and version control. The CGI access program can be implemented in C++, a suitable object oriented programming language capable of accessing interfaces to ObjectStore databases.

5

#### 5.2.4. ABI System Security

Security and access control present additional client and server requirements which are importantly part of an implementation of this invention. Security and access  
10 control can be maintained by careful selection of management policies, security software, and security hardware. These elements are described in this section in the order of authorizing and controlling access, operating system and network security requirements, and implementation language  
15 issues.

In a preferred embodiment, the primary means for authorizing and controlling access are passwords. System management of passwords preferably includes ensuring that user passwords are secure, not easily guessed, and are  
20 periodically changed. This invention is also adaptable to any other means of access control, including for example, passive and active identification cards and recognition of certain personal characteristics, such as voice. Access protection can be preferably provided by limiting access to  
25 system resources - database and file - based on a user's password. For example, access protection can be implemented in the CGI application access programs.

The operating system in clients and servers of this invention is preferably of a tested security level. This  
30 base security can be enhanced by a variety of techniques and tools that can provide increased levels of security for additional investments. Such techniques and tools include firewall machines, that is dedicated network gateways that filter incoming and outgoing packets according to content  
35 criteria, and monitoring software, such as tripwires, that observe system events for suspicious combinations. Further, encryption can help protect sensitive and valuable data from

illegitimate access by those without the key. Encryption in hardware and software can be provided according to methods known in the art, such as the Rivest-Shamir-Adelman (RSA) public key algorithm or the data encryption standard private  
5 key algorithm.

For those embodiments and materials data that download executable code segments, the implementation language importantly should address the security exposures thereby created. For example, a malevolent and knowledgeable user  
10 can create or modify the downloaded code to perform illegitimate operations within the client system or access restricted information from the server. The Java™ language is preferable in these embodiment because it now significantly addresses these problems and further  
15 improvements are constantly being made. Examples of Java™ security measures include limiting access to client system resources, particularly the file system and network connections, preventing downloaded software from 'spoofing' local software, and providing byte-code verification to test  
20 code for possible security violations. Any implementation language for an ABI system preferably offers similar or improved security features.

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### 5.2.5. ABI System Usage Metering

Each student receiving ABI instruction on a specific topic is presented with a combination of instruction, utilities, and on-screen agent interaction. Because the ABI System provides individualized interactions, each such presentation comprises a unique mixture of visual, audio, and software elements. Also, each user's consumption of hardware and communications resources differs. The ABI System therefore preferably incorporates metering technology to track the utilization of the different elements of the ABI System. Such information can be used to determine payments to the creators or providers of these elements and/or as a basis of charges to the user. Further, this information can be used by ABI System providers to determine absolute and relative usage of various components of the system. Parties interested in such information include providers of server hardware, application software, networks, instructional and tool content, authoring tools and on-screen agent animations, scripts and utterances. Finally, this information can be used to monitor system performance and utilization.

Current metering technology does not provide the detailed measure of usage that is advantageous to ABI System providers. Such technology adapted for network distribution of content is available from, e.g., the IBM Corporation, as the IBM Cryptolope, and Electronic Publishing Resources (EPR), as the Digibox.

The ABI system comprises hardware elements, standard software elements, special application software elements, and content elements typically supplied by different providers. Hardware elements include networks and other communications links, server CPUs, and disks. Standard software elements include operating systems, database packages, and communications software. Application software includes instructional playback engines, schedulers, and agent software. Content includes instructional materials, utilities such as dictionaries and encyclopedias, and on-screen agent animation and utterances.

ABI metering comprises the elements of the metering utility software, of tagging of all ABI component elements, and of the preferred methods of monitoring. The pricing and compensation model is preferably provided by system administrators. The ABI Metering Utility Software ("The MUS") measures usage and maintains usage data in a 'multidimensional usage model' during each student session. The MUS is resident at run-time on the student clients and the system server(s). In the student client, the MUS is a component function of the Session Manager with inputs derived from the Executive Software, Agent Software and the Materials Engine. In the Server system, MUS is a component function of the System Manager Software.

To facilitate metering, each ABI element is tagged with an ownership identification code similar to a product barcode. The first digits indicate ownership and subsequent digits indicate the specific component. As the elements move through the system from server to client and within the client, the use of these elements is metered. In the client software, the Materials Engine uses materials ownership tags to meter content. The agent utterance generation and visual display generation uses tags of the data snips to track ownership of on-screen agent actions. The session and screen manager keeps track of which element of the screen is active.

This invention is adaptable to any method for measuring usage appropriate to the particular component elements. In particular, four preferred methods of measuring usage are by-time, by-interaction, by-unit and by-packets. The by-packet method is performed at each server to track usage of communications resources. This method is preferably implemented by using a count of the number of bytes transferred in order to estimate the number of packets transferred. The ABI application software keeps track of counting the number of bytes transmitted to the user according to content type (i.e. system packets, instructional materials, or elf animations). Then based on the network transfer protocol used, the byte count may be converted to a

roughly equivalent packet count. Alternatively, the byte count may be used directly as a measure. In the case of multiple servers, each server sends a summary of packet transmission information to a unique metering utility server.

- 5       The by-elapsed-time method is performed at the client. In this method, the Screen Manager at the student client keeps track of the multiple simultaneous on-screen activities such as instructional materials, the elf, and the dictionary. This method preferably further monitors the active element of  
10 presentation, that is, the element performing an action or the focus for student input. In a more limited alternate implementation, the connect time of the student may simply be measured at the server. To avoid network problems such as lost connections and missed session signoffs, the System  
15 Manager application at the server additionally periodically obtains session statistics during a user session, either by polling the student client or from timed client downloads.

      The by-units method is preferably implemented either at the server or at the client. This method measures the  
20 content accessed by the client. For example in the case of instructional materials, the server records the specific lesson accessed while the client records the completion of exercises. In the case of on-screen agent actions, this method records each completed display or animation sequence  
25 or utterance.

      The by-interaction method is preferably performed at the client and records both fine-grained interactions, such as clicks and keystrokes, and the medium grained interactions, such as completed responses and metarequests. This method  
30 when combined with the by-time or by-units methods provides an indication of the relative level of interactivity of the instruction. For example, during use of instructional materials, the by-interaction methods measures the actual usage of each resource such as agent processing.

- 35       Usage of the different ABI elements is preferably metered by an appropriate method. The methods described above are not uniformly advantageous to different types of

presentation. A graphics designer might seek compensation based on the amount of time a design is on the screen, while the instructional designer might seek compensation based on the fraction of the lesson completed. Accordingly, the by-  
5 elapsed-time method is preferred for graphics designers, while the by-units methods is preferably used to record the publisher and lesson for instructional materials, the type and author for tools material, and the creators of the animation and utterance for on-screen agent actions. The by-  
10 packet method is preferably used to record the source of the network traffic such as access to the student object database or downloading of application software, instructional materials, or animation data snips. The preferred metering methods provide information needed for the typical owner  
15 compensation and user pricing models.

In its preferred embodiment, system administrators provide pricing and compensation models. This invention is adaptable to many alternative such models. One user pricing model is a flat rate based on the type of instruction being  
20 made available, similar to pricing in the cable industry. Another is based on connect time, as frequently done for Internet access, or on type and quantity of information retrieved, as is common for on-line database access.

TABLE 1A illustrates an exemplary model for compensating  
25 providers of ABI system elements. Compensation is based on metering data and an allocation model. The four metering methods are applied selectively to different providers. The allocation amounts 'a', 'b', 'c' and 'd' are externally determined.

30

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TABLE 1A: TYPICAL MODEL OR USING METERING INFORMATION

|    | PROVIDERS                           | COMPENSATION FOR PROVIDER   |
|----|-------------------------------------|---|
|    | Billing/Network                     | 'a' percent   |
| 5  | Server Hardware Providers           | 'b1' percent divided up according to number of packets with up to 'b2' percent additional if total number of packets exceed a predetermined level |
|    | Instructional Materials Providers   | 'c' percent divided up according to units   |
| 10 | Calendar/Scheduler Provider         | Up to 'd' percent based on level of interaction   |
|    | Animation Providers                 | 'e' percent divided up according to 'time on screen'  |
| 15 | ABI Client/server Software Provider | Balance of revenue  |
|    |                                     |   |

### 5.3. The Instructional Interface

20 The ABI system has interfaces for students, teachers, and administrative staff. Materials and software developers can have specific ABI system interfaces. Alternatively, such development can occur on separate systems followed by indexing and loading of the developed components into the  
25 appropriate databases.

#### 5.3.1. Student-System Interface

This section describes the structure and design of the student-system interface. This description is directed to  
30 the currently preferred implementation of this interface by a series of visual display screens. However, this invention is not so limited, and adequate alternative technologies, for example voice output with speech-recognition input, can be used to implement this design.

35

#### 5.3.1.1. Exemplary Student Screens

During materials presentation, a student sees screens of one or more screen types, all formatted in accordance with the previously described design principles. Screens are  
5 structured as a hierarchy of areas and subareas with text, graphical, animation, and perhaps video objects displayed in the subareas. Objects can either be for display only or permit student input or interaction.

An important screen type is a task screen. Task screens  
10 are used for materials presentation tasks such as homework assignments including problems, programmed steps, mastery quizzes, and drills. Table 1 and Fig. 3 illustrate exemplary components of a task screen appropriate for elementary education. Reference numbers in Table 1 are from Fig. 3. In  
15 general, in system area 302, the session manager presents objects visualized as icons permitting the student to easily access ABI system facilities. In materials area 304, object presentation including description, placement and movement, is specified by the materials designer in the presentational  
20 and sequencing sections of the materials data. The materials engine interprets these specification at run time to send display objects for display. In agent area 303, agent behavior processing formats predefined parametrizable objects, including resolution of object parameters,  
25 representing selected agent personae. The output from all selected and formatted display objects is sent to the executive software and operating system for ultimate display to a student.

30

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TABLE 1: STUDENT SCREEN DISPLAY ELEMENTS

| REF NO. | NAME OF ELEMENT        | DISPLAY OUTPUT OBJECTS  |
|---------|------------------------|---|
| 301     | Screen                 | Entire ABI display area   |
| 5 302   | --System Area          |   |
| 305     | --Customizable         | Graphics and text<br>(can be animated)  |
| 306     | --File System          | Book icons with titles  |
| 309     | --Scheduling Toolbar   |   |
| 307     | --Monthly Calendar     | Graphics  |
| 10 308  | --Clock                | Dynamic graphics  |
| 310     | --Toolbar              | Icons of tools (for<br>calculator, word<br>processor, dictionary,<br>communications, etc.)                    |
| 304     | --Materials Area       |   |
| 15 311  | --Open Book            | Graphics of book outline  |
| 312     | --Section Tabs         | Graphics with text  |
| 313     | --Exercise Area        | Text, graphics  |
| 314     | --Header               | Text, graphics  |
| 315     | --Presentation         | Text, graphics,<br>animation, video   |
| 316     | --Input                | Interactive objects<br>(buttons, etc.),<br>filling in text,<br>dragging, drawing                              |
| 20      |                        |   |
| 321     | --Navigation Buttons   | Graphics  |
| 317     | --Student Action       | Icons for Submit, Help  |
| 309     | --Sched./calendar      | Graphics for calendar<br>with text of student<br>schedule, icons for<br>scheduling options                    |
| 25      |                        |   |
| 303     | --On-screen Agent Area |   |
|         | --Audio                | Synthesis of spoken<br>utterance  |
| 318     | --Text Message         | Text utterance  |
| 30 319  | --Visual Persona(e)    | Appearance integrated<br>with audio, graphics<br>background effects<br>Interaction<br>with other screen areas |
| 320     | --Agent Request        | Agent meta-request icon,<br>generates pull-down<br>menu of meta-requests                                      |
| 35      |                        |   |

In more detail, the task screen of Fig. 3 includes in system area 302 student customization area 305. In the

customization area, the student can display objects given by the agent as rewards for student accomplishment. These objects can include text, as illustrated here, graphics, or animations. Another part of the system area is file system toolbar 306 displaying accessible files as icons in a "book-on-shelf" metaphor. This invention is adaptable to other reasonable file system display metaphors. Here, for example, the book icons represent a file personal to the student, a file holding ongoing instructional materials, a file of e-mail, and files for tools such as a dictionary and group activity. Below file system toolbar 306 is toolbar 310 for tools the student has access to. Illustrated here are icons for a calculator, a word processor, communications, and starfish, a general purpose language tool.

15 "Starfish" are a visualization tool for semantic networks that can be available in an ABI System. A semantic network typically consists of nodes linked to other nodes by semantically significant and named links. A starfish tool visualizes such a network for a student by displaying the node centrally in the body of the starfish with the node's links displayed as arms of the starfish. For example, a dictionary represented as a semantic network might include a node for each word with links to similar words, opposite words, root words, and so forth. A dictionary starfish

20 displays a word in its body. Each selectable arm is labelled with a category - synonym, antonym, pronunciation and so forth. Clicking on an arm causes the corresponding word(s) to be displayed or spoken. Such a tool provides integrated display of diverse knowledge structures for a student.

30 The scheduling/calendar tool is an important tool that is always available. Exemplary icon 309 illustrated for this tool has calendar part 307 and clock part 308. Selection of each of these parts brings up daily and monthly scheduling functions. These function can either prescribe the student's

35 next activity or permit choice where the student has excess time or demonstrated personal scheduling ability.

In materials area 304, instructional materials, tools, and communications materials display their content. Illustrated in Fig. 3 is page 3 of an exemplary mathematics homework. Instructional materials are advantageously  
5 structured as a book of exercises and items, emulating current textbook and workbook practice. In this case, section tabs 312 permit the student to navigate the homework book by sections, and page buttons 321 permit the student to navigate the homework book by page. Also present is toolbar  
10 317 of available student actions, which for homework includes submit and can, if the agent permits, include help and hint requests. The format of a materials page is advantageously standardized. An exemplary standardization has header information 314, presentation 315, and interactive input area  
15 316.

On-screen Agent area 303 allows the student entry of meta-requests and allows the agent to display synchronous or asynchronous meta-responses. This exemplary area illustrated in Fig. 3 comprises meta-request button 320 which the student  
20 can activate to display a list of currently available meta-requests. Student metarequests are generally allowed by the ABI system at any time. Requests may occur at the beginning, middle or end of instructional sequences, in choice screens, in tools, in group communications, or in the calendar. Agent  
25 metaresponses are individualized and context dependent. Typical metarequests are illustrated in Table 1B. As an example of context dependence, if the request 'Where am I?' occurs within a lesson, a graphic representation of the lesson will be shown; whereas if the same request is made  
30 between lessons, a graphical representation of previous lessons and new lessons will be shown. The agent software attempts to respond based on the user's intention and uses the context and previous requests to infer the reason for the current request.

35

TABLE 1B: TYPICAL METAREQUESTS

|    | TYPE   | METAREQUEST                             |
|----|--|---|
| 5  | Temporal: Time remaining in current unit/session/days work                           | 'How far along?' 'How much longer?'     |
|    | Marker: name and description of current lesson/exercise; relative position in lesson | 'Where am I?'                           |
|    | Pause: Repeat of instructions: summary of what has been done                         | 'Say it again.' 'Say that another way.' |
| 10 | Performance: summary of work in current lesson                                       | 'How am I doing?'                       |
|    | Choice: Branch to take. e.g. which lesson to do next                                 | 'What do I do next?'                    |
|    | Purpose: function of current lesson  | 'What is this for?'                     |
| 15 | Resources: assistance available at this point  | 'I need to hint.' 'I need help.'        |

The instructional materials notations provide a framework for the agent software to keep track of the relative position of the student in the lesson. This same information is also available to the teacher for lesson preview and annotation.

The remainder of area 303 is for agent meta-responses, which importantly have multi-media structured into personae. Illustrated are text message 318 and visual persona 319 that typically includes animation. Also possible is audio output, either text-to-speech or generated from audio files.

Fig. 4 further illustrates an exemplary screen interaction between the materials and the agent. Fig. 4 shows only the content of materials area 501 and on-screen agent area 502 of the complete display screen of Fig. 3. A mathematics homework material is displaying item presentation 503 with input selection buttons. The student has selected wrong input button 504. At this educationally significant event, the materials send to the agent several messages generated by notations in the materials data. In response, the student's agent has chosen to act as illustrated. First,

it displays text 506 of the rule violated by the student answer. This text was sent to the agent by the materials in an event message for its use. Second, the on-screen agent points 505 to the screen location of the error. This  
5 location was also sent to the agent by the materials. Third, perhaps in response to a previous high or increasing error rate of the student, the on-screen agent presents a meta-response 508 commenting on the pedagogic nature of the student's error. Further, it activates a persona 507 to  
10 engage the student's attention. This persona can advantageously include animation, audio, and speech output of the displayed text. Thus, the agent software integrates speech utterances, visualization, display of text and graphics, and animation into a persona display for  
15 highlighting an educational event that the agent determined important based its processing of the current input, past student inputs in this lesson, and the student's pedagogic model generated over several sessions.

Other screen types are of importance in an ABI system.  
20 For example, tools can have distinctive screen types appropriate to their nature, such as a calculator image. Choice screens can be used at the transitions between instructional sequences. They summarize what instructional materials have just been completed, announce status  
25 information, and list any materials choices now available to the student. These choices can related to instructional materials to be undertaken next or to optional, non-instructional materials, such as exchanging credits for time in a game room, access to e-mail, and so forth, that can be  
30 available to the student.

#### 5.3.1.2. Student Actions

The inputs of a student or other user of the ABI System are preferably classified as requests, meta-requests, or  
35 data. A student request is an input directed to materials or to the system seeking a specific action. Student data is an input responding to a system request for information. For

example, student requests include an input to the system to start the calculator is a request; or an input to certain materials to submit completed homework to the teacher.

However, input of numbers into the calculator is data. This invention is adaptable to a further particular type of data input, termed semiotic, in which the student selects certain signs or symbols to provide input. Semiotic input is particularly advantageous when the agent requests the student to report his feeling or appreciation for a particular educational event. Meta-requests are inputs directed to the agent seeking specific actions. For example, student input to the agent seeking hints during the current materials is a meta-request.

Displays produced by this invention are preferably classified as applications, responses, meta-responses, or questions. Application display occurs upon system initiation of an available material, for example, an instructional material or a tool. Application display usually occurs in response to a student request, but can also occur on system initiative. For example, the agent can request the system to make a tool available to the student. Responses are all displays produced by materials or by the system. For example, responses include materials presentation display and display on the adequacy or correctness of student input. Meta-responses are all displays produced by the agent. These can be synchronous, generated by responses to a student meta-request, or asynchronously, generated by events sent to the agent from the materials. Questions are a particular form of response or meta-response which seek further student input. Questions engage the student in a form of a dialogue which is an integral component of the tutoring interaction.

Fig. 5 illustrates an exemplary segment of the interaction of the student and the system that can occur during a mathematics homework. It illustrates both how responses and requests are distinguished from meta-responses, and meta-requests and also how the agent, through its observation of the student's current situation and its

contact with past student history, is able to guide the student better than the materials alone, which are only aware of the current context. This display is individualized to the student's current and past performance and preferably  
5 uses realistic, life-like on-screen personae to engage the student. Displays from the ABI System directed to the student are indicated generally on the right; inputs from the student directed to the ABI system are indicated generally on the left; and time increases downward. The diagonal arrows,  
10 as at 401, indicate that the message at the arrow's tail leads to the message at the arrow's head.

This illustration begins with response 402 from the mathematics homework materials suggesting that the student use the calculator tool. The student responds with request  
15 403 which selects the calculator icon to request the calculator. Calculator application 404 is then activated and displayed by system components. Data 405 is a student input to which the calculator tool, and response 406 indicates a student error. This response was apparently not sufficiently  
20 informative, and data 407 is a repeated incorrect input to the calculator tool. The student's agent observes the course of this interaction as the calculator tool sends event messages to the agent. Upon observing the repeated wrong input, the agent intervenes with a asynchronous meta-response  
25 408 summarizing recent student inputs. The student responds with meta-request 409 to the on-screen agent for help, since the tool responses were apparently not sufficiently helpful. The agent's synchronous meta-response 410 suggests for consideration an entirely different approach to correct the  
30 student's recent error.

#### 5.3.1.3. System Responses

The following general principles preferably guide system and materials responses and agent meta-responses. First,  
35 some display is to be made on every user input, if only to echo a character or mouse click. Second, a user is never to be left in doubt about the status of current tasks. For

example, the system preferably provides task specific hints or suggestions if no user input is received in a time period adaptively determined. Third, all responses reflect the current context.

- 5 Further, importantly, aspects of system responses should be adapted to the particular student audience, from elementary to adult education and including special classes of students. This tailoring can be set by the teaching or administrative staff. One adaptable aspect is the language
- 10 level and the language of system responses - for example, the vocabulary and language of help services, messages, and tutorials - is preferably adjustable. Another important adaptable aspect is the type of personae of the on-screen agent is preferably adjustable. The types of encouragement,
- 15 level of jokes, and so forth, depend closely on the intended student population and are advantageously adjustable. Further, tools are also adaptable. Each tool is also advantageously enabled or disabled for each student. Mail and communications tools, for example, can be made
- 20 unavailable for the lower grades. File creation and deletion can require strict controls. Also, certain tools can have differing complexity levels suitable for differing student levels.

- In addition, certain ABI system components have
- 25 particular preferable and advantageous features. These are listed subsequently. Importantly, meta-response selection is preferably shaped in view of the student's past baselines of speed, performance accuracy, modality, as specific to the type of materials. Moving average functions, in which recent
- 30 values are given higher weight than earlier values, can be used advantageously to generate baselines of performance and timing. The timing of meta-responses is preferably based on student data object fields that record the amount of help asked for in the past and past performance provided.

- 35 Further, the pacing of meta-responses is advantageously context sensitive. For example, remediation should be offered only in case of repeated error or hints offered



asynchronously only after a relatively long period without an answer. Also, previous student interactions should be utilized. Repeated requests for hints should be noted and dealt with perhaps not with another hint but with  
5 remediation. The rate of prompts, advice, and hints should be adaptively adjusted on the basis of ongoing performance records.

The actual content of a meta-response can be adjusted to the current situation by filling in parameters from event  
10 messages sent from the materials. See *infra*. The Instructional Materials Interface Standard ("IMIS") is a key element in providing information to the student in response to inquiries such as "Where am I?". The system then uses the information in the IMIS to respond, "You are halfway through  
15 the drill and practice on fractions," for example. A student request for further information can elicit a graphical response. The graphical responses reinforce the virtual tutoring aspect of the system by providing a greater level of detail in a format similar to that presented by a human  
20 tutor. The format of the graphical method used is individualized to the student's past use of system components such as previous graphical metaresponses and tools such as the scheduler/calendar.

The structural information for the agent software to  
25 construct graphical responses is derived from lesson notations, previous student performance, previous agent responses (including graphical responses) and the scheduler/calendar. Marker requests use general notations for the type of lessons and specific notations for  
30 prerequisites. Temporal requests use notations of expected time together with profile information on individual performance on that type of material.

Typical predefined graphical response templates include roadmaps (perhaps in the form of a train and subway map),  
35 charts, table, graphics and icon flowcharts. Colors can be used to show relative levels of performance, urgency or dependency of elements. In response to a 'How am I doing'

request, green might indicate good performance; yellow, adequate performance; and red, needs immediate attention. Similarly, the shape of the icon might indicate its function such as a diamond for caution or a hexagon for stop.

5        Figure 12 illustrates an exemplary dialogue starting with the student metarequest 'where am I?'. The on-screen agent then make a metareponse containing a summary of the student's progress, for example "You are one quarter through the lesson on adding fractions." Next, the student might  
10 request further information. Preferably the on-screen agent will point to the location on the diagram and say "You are here." If the student then clicks on an element of the chart, the agent will provide further information. For example, clicking on the Practice Box will provide a  
15 metareponse containing a flowchart of this upcoming activity, as generally illustrated.

#### Preferable Calendar/Scheduler Responses And Their Selection

The calendar scheduler is advantageously capable of  
20 providing the following responses. These are controlled by schedule data contained in the student data object and are processed by the calendar/schedule tool.

1. Schedule reminder responses, which remind the student of deadlines for materials tasks in the system or for  
25 external activities, such as getting a parent's approval for a class outing.

2. Task sequencing suggestion responses, which suggest an order of assigned tasks based on student history and on the assigned priority and deadline.

30        3. Timing estimate responses, which estimate how long a task will take based on timing information entered as part of task in the instructional materials and on past relative performance for this student.

In one embodiment, the ABI system provides for of  
35 scheduling initiative to be divided between the student and the system. Settable task schedule parameters permit, at one extreme, the student to have complete scheduling control,

able to initiate and to exit any activity at will, and limit, at the other extreme, the student to work on only those materials that the system schedules. These schedule parameters include those controlling the tools and options  
5 available to the student while performing a given task and those requiring the student to perform background reading or remediation. Important initiative parameters include the scheduling values of task priority value and deadline. If the priority and date are not both "off", those tasks with  
10 greater priority and earlier deadline are automatically scheduled for the student. If these values are "off", the student has control of task scheduling.

The system of this invention also includes a central list of timed activities, perhaps stored on the server  
15 systems, to be performed by the system. These can include regular times for the generation and printing of standard reports or for the broadcasting messages concerning group activities such as spelling bees. These timed activities can be performed by scheduling software which compiles the timed  
20 activity lists and initiates the listed activities at their listed times. Such scheduling software can be similar to the "at" utility in UNIX operating systems.

#### 5.3.2. Teacher/Administrator-System Interface

25 The teacher or teacher's representative plays an important role in the ABI system. The teacher uses the system to perform such functions as entering initial profiles in student data objects, assigning students to subgroups, previewing, annotating and scheduling assignments, reviewing  
30 and commenting on completed homework assignments, and reviewing summary reports.

The agent of the student is also an agent of the student's teacher in that the student's teacher controls key parameters in the student data object, which in turn controls  
35 agent actions. The teacher customizes the ABI system by setting student data object parameters, assigning and prioritizing assignments, and customizing materials.

Important teacher activities are included in the following list.

1. The teacher initializes and exercises continuing control over important data in the student data object, and  
5 in this manner supervises the student's use of the system. For example, the teacher controls the access and level of tools available to the student and limits the extent to which the student can alter agent personae.
2. The teacher controls the student's use of the ABI  
10 system by assigning, scheduling, and prioritizing the student's access to the materials. This is accomplished by teacher control over the schedule subtype in the student model object. For example, the teacher can schedule tasks that must be completed on the ABI system, schedule non-system  
15 tasks, remove tasks or modify their priorities.
3. The teacher can customize materials available to the students. The extent of routine customization includes modifying sequencing of instructional lessons, elements, and items, choosing the homeworks the student must complete,  
20 specifying the formats of homework assignments having some student discretion, such as reports, sending messages to students.
4. The teacher's class management is aided by a facility to send messages, reminders, hints, etc. to students  
25 using the ABI system e-mail facilities.

The system can advantageously assist the teacher in homework management. Once the student completes and submits a homework assignment, a printed copy can be made for the teacher and the student. The homework assignment can be  
30 graded by the ABI system, if answers were provided as part of homework material. The teacher can add comments for the student, if homework is viewed online by teacher.

The system can advantageously also provide the teacher with summary and detail reports for each student and class.  
35 These reports can be immediately available online or printed for later review. As known in the art, reports can contain both current and cumulative data on instructional progress

and homework assignments. The reports can also flag patterns of deficiency in a student's homework and problems in a student's instructional progress. In a preferred embodiment, these reports are generated from the database of student data  
5 objects on the server systems.

Additionally, the teacher can be a student. A teacher can benefit from training in the use of the ABI system in general, in the procedures to customize materials, and in the characteristics of the particular materials used in that  
10 teacher's class. This training can advantageously be packaged as instructional materials directed to the teacher which are otherwise similar to student instructional materials. In this case, the teacher, like the student, has accessible materials, a teacher data object recording the  
15 teacher's progress and pedagogical characteristics, and an agent using this data object to guide the teacher's training and guide the teacher in the use of the system.

Other actors, such as school administrative staff, parents, and researchers, can play a role in the ABI system.  
20 Administrative staff can have privileged access to certain data items in the student and teacher data objects and other system data, which permits them to assign students to courses, to assign students to teachers, and to establish instructional performance standards and criteria which the  
25 students must meet to complete their materials. This staff can also receive online or paper reports on the progress of students in the schools, the effectiveness of teachers, and the usefulness of the particular materials assigned.

### 30 Reports and queries

Generation of reports from databases, either relational or object-oriented, is a standard programming task. The key elements of this task are the selection of data to appear in the report, the way in which selected data is to be presented  
35 whether in a summary form, a detail form, or both, the format in which the data is output, and the layout of data output elements on the screen or page.

The teacher and administrators require several types of reports. Periodic reports need to be generated at regular intervals. These vary according to population: by student, by class, by grade, by school. They also vary by subject.

5 The reports can present/summarize complete sets of data or only data exceeding stated limits. Some of these reports fulfill mandatory reporting and record keeping requirements, and some are sent to parents. The ABI system also provides teachers and administrators with standard querying and report

10 generating capabilities.

If appropriate, parents can also be actors in an embodiment of the ABI system. A student's parents can be given access to certain fields in their student's data object in order that they can receive rapid information on their

15 child's assignments and performance. This information can be made available at home on the same client system that their student receives instruction and homework.

Finally, educational researchers can receive certain access to ABI systems in order to research the effectiveness

20 of educational theories and methods. For example, they can efficiently compare the effectiveness of various educational paradigms in certain instructional contexts by receiving reports relating to students pursuing materials constructed according to the paradigms of interest.

25

### 5.3.3. Instructional Designer-System Interface Designer Interface Overview

Materials, in particular instructional materials, are authored by instructional designers. Authoring of materials

30 can be done on the system on which the materials are to be used, or alternatively, on a separate system. Generally, an instructional designer authors materials including, for example, computer assisted instruction as known in the art, computer assisted exercises such a homework or simulation,

35 and computer managed student instructional tasks which can involve work with several materials. For all materials, the

student's agent must be informed of the sections completed and skills acquired in standard formats.

#### Designer Interface Details

5       The ABI system provides an environment in which the student's agent is available to control materials presentation and guide the student to improve educational outcomes. This environment includes facilities to present assignments, assess responses, probe for prerequisites, offer  
10 assistance with tools such as dictionaries, and score unit mastery quizzes. The system can advantageously include conventional forms of homework, such as worksheets, as well as new types of homework, such as group-based homework, and formats previously too time consuming for teachers, such as  
15 criterion based rather than fixed length or interactive rather than prescriptive. Advantageously, the system structure can accommodate existing forms of computer assisted instruction by embedding such existing instruction in materials of this invention which contain notations and  
20 generate agent event messages.

      All authoring information below can be provided by the instructional designer, if preferred. In this case, defaults allow the teacher to enter only overriding information where needed. Alternatively, the teacher can be allowed or  
25 required to make various degrees of customization. In this section, the term "exercise" means a single unit of an instructional task.

      The run-time conversion of materials with descriptions of text, graphics and animation advantageously is performed  
30 by methods commonly used in interactive multimedia Authoring Software. Existing authoring programs let the author specify the attributes and behavior of multiple independent display objects through such programming paradigms as visual programming or scripting languages. For example, to display  
35 a button or other selectable object, a user of authoring software specifies such characteristics as position,

attributes such as size, shape, color, and label, and the function invoked by the object selection.

Among the most widely used of the many available products are Macromedia's Authorware and Director,

- 5 Asymetrix's Multimedia Toolbook and Aimtech's IconAuthor. These programs have been documented by their manufacturers and other writers (Sims, *Authorware with Style*; Swearington et al., *Macromedia Director Design Guide*; Hill, *Using Multimedia Toolbook 3.0*).

- 10 The process of authoring an instructional task is advantageously described sequentially to include the steps of, for example, defining the task, defining each exercise, judging student inputs, defining exercise completion, and augmenting the materials with notations for the agent.

- 15 In the authoring step of defining the task, the instructional designer advantageously provides information including initial instructions for the entire task in a written and preferably also a spoken format with alternative wordings as necessary for special classes of students. The  
20 designer also provides materials sequencing in accord with the education paradigm chosen. Instructional sequencing is appropriate for interactive instruction with feedback. Homework sequencing can include a fixed order; a student defined order; a student defined order assisted by teacher  
25 prioritization into such priority groups as essential, important, or optional; and sequencing defined by performance to criterion on individual item subtypes.

- In the authoring step of defining each exercise, the instructional designer advantageously provides information  
30 including the following. The designer chooses names for this task and exercise, its prerequisites, and the skills to be acquired in accordance with school system standards so that the agent can meaningfully track student performance and provide helps, hints, and remediation. Next, the designer  
35 provides student instructions for the exercise, preferably in both spoken and written formats. Next, the designer specifies the presentation of the exercise by creating



graphics and text for the exercise and by specifying their display attributes. Next, the designer defines allowable user inputs, the data type of input, and the display areas in which input is allowed. Finally, the instructional designer  
5 provides hints. Hints preferably include optional hints offered on student request or student inactivity and hints offered by the agent in case of totally inappropriate actions.

In the authoring step of judging student inputs, the  
10 instructional designer advantageously provides information including the following. First, the designer defines standards for the completeness of requested inputs and actions, possibly none, in case of incomplete inputs. An exemplary such action is suggesting the completion of omitted  
15 inputs. Second, the designer selects how inputs are to be judged and the possible judgements, for example, correct, near miss, incorrect, and so forth. Finally, the designer selects error responses to individual input elements or an entire exercise. These responses can be uniform or can  
20 reflect the specific wrong answer. Error responses include retry policies and selection of remediation paths. Remediation can be item sequencing options given on the basis of retry outcome.

It is preferable that response judging be performed  
25 according to certain standards established for a particular implementation of this invention. Thereby, the agent can monitor the student's pedagogic characteristics in a uniform fashion across all standardized materials. Accordingly, a first step in input judging can be, where appropriate,  
30 checking the data type and perhaps range of an input. For example, checking that a fraction is entered in response to a fraction addition problem. Appropriate feedback can be given if the wrong data type or range is input. Single student inputs can include entry of a single text or numeric element,  
35 movement of a single display object, selection of a single display object, or drawing a line or curve perhaps encircling a display object.

A second step in input judging can be classification of a suitable input in standard error categories. In an exemplary embodiment, this can be performed by providing a pattern corresponding to a correct answer. The patterns can  
5 be a template appropriate to the suitable input, such as a text template or a spatial template. A pattern matching procedure selected from a system library of such procedures can be executed to match the input to the pattern. The output of the system matching procedure is advantageously  
10 selected from a limited number of standard judgements of correctness and partial correctness. This judgement is then communicated to the agent in an event message in order for it to guide its student and adapt its pedagogic model. This invention is adaptable to templates and pattern matching  
15 procedures known in the art. Patterns can include one or more parametrized text templates, spatial templates defining the relative positions of objects to be moved by the student, selection templates specifying patterns of selections. Further, spatial templates can include outlining areas of the  
20 screen, shapes of drawn objects, maze traversal, and tool inputs.

Turning to the authoring step of defining task completion, the instructional designer advantageously provides information including standards for input, exercise,  
25 and task completion. The materials can require a certain minimum completion before allowing homework submission to the teacher.

The final authoring step is augmenting the materials with additional notations for the agent. These notations  
30 concern task and exercise subject, skill classifications, and definition of the educational paradigm embodied in the sequencing logic. It is performed by instructional designers or knowledgeable teachers, and is expressed as notations in the materials that generate event messages for the agent and  
35 that reference control parameters set by the agent for control of materials sequencing. The notations so entered communicate various types of information to the agent.

Exemplary types include characterization of assignment by type of task, subject, elements of subject covered by task; comparison between exercises in same assignment by similarity and difficulty; the subject matter prerequisites to determine  
5 what the student may or may not have mastered based on which exercises are answered correctly; system knowledge prerequisites; and scheduling information such as average and expected time to complete.

#### 10                    5.4.    ABI System Software Structure

This section describes in a more detailed fashion an exemplary structure for the software components previously described in a more general fashion with reference to Fig. 2. Subsequent sections describe particular components in an even  
15 more detailed fashion. The structure described here is exemplary. This invention is adaptable to other structures with other allocation of the functions of this invention to different modules. Such alternative structures are easily designed by those of skill in the arts.

20        This section first describes the principal client software and data components and the conceptual hierarchy which reflects their interaction. Next, the structure of the executive software is described. Finally, the flow and processing of events through the system are described.

25

##### 5.4.1.    Student Client Software Structure

Fig. 6 illustrates the principal client software and data components and the conceptual hierarchy which reflects their interaction. The links illustrated represent principal  
30 procedure call or class dependencies among the components. At the root of the hierarchy is operating system 601, which has been previously discussed in connection with the preferred client hardware. The operating system ("OS") includes the operating system proper together with implementation  
35 languages and their class and function libraries with associated controls. At the next level is executive software 602 ("ES"). This software collects a number of components

which customize the operating system to the requirements of this invention and also extend it, if needed. For example, all OS task creation is processed through an ES task control facility to insure that the student accesses only permitted materials. The ES software also provides a preferred animation facility and controls client startup.

Session and screen manager 603 is always present on a client system. This component partitions the screen into the areas for the principal system components, as has been generally illustrated by the exemplary screen of Fig. 3, and controls the system area, area 302 in Fig. 3. Thus, upon student selection of an icon presented in the system area requesting the ES to start the function represented, it turns checks with schedule/calendar 607 whether the student is currently permitted to access this function before continuing with OS task creation. The system manager also presents whatever reward graphics and animation the student has been granted access. These functions are performed by calling the object level I/O facilities of the OS and ES.

Also always present on a client system is student data object 611 for the student in session on the client. This object, preferably containing all the permanent read-write data in the ABI system relating to the student, is downloaded from the server student database when the student logs onto the client. Preferably, this object is divided into subtypes, and those only those subtypes referenced are downloaded as required. In an alternative implementation where the permanent student data is stored in more than one object, each object is downloaded from its database as required. As indicated by double headed arrows 608 and 614, various ABI system components reference and update data items in the student data object.

Schedule/calendar component 607 is important for management of the student by other system actors, such as teachers and administrators. It is a tool that is always active whether or not it has a screen presence. Activities for the student, represented by activity description,

priority, and deadline, are entered into the schedule/calendar data subtype of the student data object by teachers or administrators. Optionally prerequisite information can also be entered into the schedule/calendar

5 subtype. This component uses this schedule/calendar subtype data as well as the time expected for the student to complete an activity, as determined from the student's past performance also stored in the student data object, in order to determine whether certain activities, such as particular

10 instructional materials, should be automatically started by the ES without any student intervention. In cases where the student is permitted greater initiative, the schedule/calendar can permit OS task creation requested by the student, as by selecting an icon. This component also

15 provides, on request, prioritized lists of tasks for the agent to present to its student when the student asks for advice on what to do next. It uses priority and deadline information and time-for-completion data computed using data in the instructional materials and student data object.

20 The materials are represented in the ABI System by materials engine 604 and materials data 605. As previously described, the materials data comprises objects for display output or student input, sequencing logic controlling object display, and notations which when referenced by the

25 sequencing logic during object presentation generate event messages for the agent. Materials data is advantageously grouped into "entries" comprising those objects, logic sections, and notations related to the display of a single screen or a few screens related to a single educational item.

30 The materials data also preferably include a special header or initialization entry with important notations that communicate to the agent the educational paradigm adopted by these materials and can inform the agent of the control variables to which it is responsive. Such header or

35 initialization messages are also preferably sent to the agent if the materials change their education paradigm. In a preferred embodiment, there is one common materials engine

604 which presents a plurality of materials data 605. In alternative embodiment, there can be specialized materials engines for various classes or types of materials data.

Materials engine 604 downloads the entries of materials  
5 data 605, interprets the sequencing logic, displays objects as requested, and references embedded notations generating the requested event messages to the agent. Standard facilities of the OS and ES are used for object presentation and for routing any input to the materials. Input is  
10 processed according to specifications in the sequencing logic. In a preferred embodiment, the agent controls the materials by setting shared global variables which the sequencing logic checks. Such shared global variables can be made available by OS interprocess communication ("ipc")  
15 facilities, such as shared memory. The materials engine can be any program implementing these requirements, in particular an extension of available commercial authoring tools and engines, such as Macromedia's Authorware.

In an alternative embodiment, the materials are not  
20 separated into an engine and a data component but consist of one unitary component for each material. In this embodiment, a process similar to compiling creates a single executable materials component. This invention is equally adaptable to other implementations of the materials that generate agent  
25 messages and are responsive to agent control according to the requirements outlined herein.

Agent processing is divided into two components, agent action processing 609, which determines agent display actions in response to events, and agent behavior processing 612,  
30 which transforms display actions into displays of personae to the student. In a preferred embodiment, agent action processing is rule based and event driven. Rules in rules tables 610 are evaluated using parameters both communicated in event messages from the materials or the student and  
35 retrieved from the student data object. These rules propose candidate actions and then weigh and select a final set of agent actions from the candidates, which are communicated to

subsequent agent behavior processing 612. Agent processing also sets global variables for materials sequencing and control. A side effect of this processing is the updating the student data object with information from the materials  
5 event message.

Agent behavior processing 612 constructs an on-screen agent display based on the actions determined in agent action processing. In a preferred embodiment, this processing is based on behavior tables 613. Utterances, text or voice, and  
10 affects are selected from tables based on the determined final actions and refined with parameters included with the actions. The utterances and actions are sent to the selected agent persona object, which creates the agent display of the selected personae using the utterances and effect selected.  
15 Data is referenced and updated in the student data object by this processing, in particular fields reflecting the student's agent personalization choices, such as the desired personae, and fields reflecting recent agent behaviors.

Also illustrated is communication materials 615. These  
20 materials manage and provide resources for various group activities, such as student tutoring, group work with particular materials, and group contests.

#### 5.4.2. The Executive Software

25 The executive software ("ES") collects together a number of components which customize the operating system to the requirements of this invention and, if needed, also extend it. ES software implements common and special facilities. Exemplary common facilities include task control,  
30 communications, and I/O facilities; exemplary special facilities include a preferred animation facility and a client logon and startup facility. In a preferred implementation, ES software is built as frontends, wrappers, or extensions to available OS software components. For  
35 example, certain facilities can be implemented in C or C++ and directly call OS interfaces, such as the Windows™ graphics device interface or its extensions. Other

facilities can be built as classes using available implementation language libraries, such as the packages in Java™ 1.0. Yet other facilities can be provided directly as part of software packages, such as the display I/O functions  
5 present in commercially available authoring packages.

The task control facility manages the startup of system components. First, it verifies that the student is permitted to activate a requested component by checking schedules and priorities with the schedule/calendar tool. Indirectly, the  
10 student's agent can be queried to determine if this activation is reasonable. Next, if permitted, this facility manages the loading of required software and data objects from server systems. Finally, task control then starts up the component by making any necessary OS calls. Task control  
15 also notifies other system components at task terminations.

The communications facility manages network communications and provides whatever client-server or file server protocols are not present in the OS. Such protocols might include HTTP V2.0 with URL name resolution. It  
20 maintains all necessary network sessions, including sessions with the three major classes of servers, student data object servers, instructional material servers, and executable software servers. Data snip libraries can reside on any of these server classes. In alternative implementations these  
25 servers can be on one or several physical server systems. Finally, this facility handles all remote access requests for information including requests for downloading and uploading.

The I/O facilities includes input and output display handlers for object level display I/O. The display handlers  
30 receive object level requests for text, graphics, video and audio and translate them into whatever interface is supported by the OS. The input handler receives low-level inputs from the OS input handlers and processes them according to the current screen format. In certain cases, it can directly  
35 call the output handler to perform immediate feedback actions, such as highlighting or dragging an object. In other cases, it can pass I/O event messages in an appropriate



format to the system component owning that screen object, for example, the on-screen agent. The output handler receives object presentation specifications, such as system owner, position, characteristics, size, any animation information, and whether the object is an input focus, then updates any necessary screen mapping, and generates OS requests to display the object. An example of such an object specification includes a selectable text field object with specified contents, perhaps scrollable, displayed by a particular instructional material.

Exemplary specialized ES facilities are animation and client startup. It is preferable that the client system support animation, which is a connected and timed sequence of displays potentially calling on all display modalities available, and other timed presentations. Although this invention is adaptable to any suitable animation facility, a preferred facility presents a script based interface.

The inputs to an animation facility are scripts which comprise object display commands, the timing of the object displays, an input specification of how any permitted user inputs are to be handled, and the types of events to be returned to the initiating system component. Examples of display events include user input causing script branching and termination or interruption. The animation facility receives a script from another system component, requests downloading of necessary display objects, for example from data snip libraries, interprets the timing specification, and sends request to the input and output handlers.

The ES startup facility is described herein with respect to a student client to run on a network attached computer. Startup is similar for other client systems, including teacher and instructional designer clients. Each component of the ABI system must be downloaded from a server when needed, if as is typical, no component of the system is resident on a client prior to startup. The initial step involves the student accessing any client attached to an ABI network. Accessing can involve as little as powering-on the

computer and requesting startup of the system on this client. Preferably, accessing by a student user begins by accessing the server with the system manager, for example, using a standard intranet browser which can be resident on the client  
5 or downloaded by a power-on bootstrap process. The student logs on to the system manager, which then performs authentication, for example, by means such as password or identification card. Upon successful authentication, the system manager downloads and starts the ES. The ES then  
10 initiates necessary communication sessions, including those with the system servers, and then downloads the session manager software, subtypes of the student data object, the agent software, and the scheduler/calendar tool software. The session manager presents the student display in a form  
15 depending on student preferences in the student data object and receives input from the system area of the display. The scheduler/calendar in cooperation with the agent then determines what materials the student is to be presented with or can select from. Finally, the materials data and engine  
20 are then downloaded and the substance of the student session commences.

Presentations of personae or merely appropriate coherent responses can be created from audio and video display objects downloaded from a server and referenced upon demand. These  
25 display objects, or data snips, can be linked into groups corresponding to the particular presentations. Further, these linked groups can include small pieces of code that allow for a branching and interactive short meta-response. Thus, one meta-response can include opportunities for student  
30 input with the next display object being chosen in response to that input. Each of these groups is catalogued and referenced as that persona behaving in a particular manner.

#### 5.4.3. System Event Processing

The ABI System on the student client, and on other clients, is advantageously organized to wait for student and timer input events and then to respond appropriately to these 5 events. This is common current practice for constructing interactive systems. However, this invention is adaptable to practices that might be developed in the future for constructing interactive systems as long as the principal system components and their mutual interactions as previously 10 described can be represented in such a future practice.

With reference to Fig. 7, this section sequentially describes the system processing of an input event and its consequences from initial input until the system waits for the next event. This description provides detail of how the 15 system components communicate with each other and of how information and control flows through the system. More detailed description of the individual components appears in following sections.

Fig. 7 conceptually illustrates control flow and event 20 processing in a student client. Generally, at the left of this figure is relevant data; in the center is processing steps; and at the right are I/O events. As is apparent from the context, the arrows in this diagram represent either data references or control flow. The control flow is at times 25 implemented by information bearing messages and at other times effected by standard ES and OS system calls. Further, this figure is directed to the processing of those components that interact with the student's agent. Those components, such as the session manager, which do not interact with the 30 agent can be constructed according to standard interactive techniques (see, e.g., Petzold, 1996, Programming Windows® 25, Microsoft Press, Redmond WA).

Thus, at wait point 701 the system waits for the next student input or timer event. This wait commences at wait 35 points 707, 713 and 717 after the system completes processing of the previous event, or possibly after system startup. Upon receiving an input event, ES I/O handlers 702 decide

whether the event represents an action without significance for other system components. For example, the event can be a student action causing only the highlighting of an object or a timer event directing an animation. Such events can be  
5 entirely processed by the I/O handlers, and system waiting resumes at 701. If the event represents a student request for the materials engine 703 or a meta-request for the agent 711, the I/O handlers format it appropriately and communicates it to the correct component owning that input  
10 object. If the event represents a time interval set by one of the materials engines or by the agent, it is formatted and passed to the requesting component. In the case of group work, the event can be generated on a remote computer system and transmitted over a network link in order to reach the  
15 local I/O handlers.

The I/O handlers format event messages into the format expected by the component they are directed to. They include in each message an indication of the type of student action or time interval along with any input information from the  
20 action. One input event can generate several events messages.

Herein, messages directed to materials engines 703 are considered first; messages directed to agent action processing 711 are considered second. Although Fig. 7  
25 illustrates two materials engines, one engine or more than two engines are possible on a system from time to time. Regardless of the number of materials engines present, event messages are communicated to the correct engine. The materials engines 703 process a plurality of read-only  
30 materials data 704 representing instructional materials, tools, and communication materials. As indicated by arrow 725, these engines also access control information determined by agent action processing 711. This control information can be accessed in any convenient manner, such as by an exchange  
35 of messages or by referencing parameters stored in a shared memory region. This information controls the materials engines at educationally significant points during their

materials presentation. Optionally, materials engines 703 can also access remote databases 705 and other remote resources available through the system network. The engines use these two sources, and optionally three sources, of input to cause presentation 706 to the student of, for example, an instructional lesson, a homework exercise, an instructional tool, or a joint educational contest. This presentation uses the I/O handler of the ES and OS to generate actual student display.

10 As indicated by arrow 727, the materials engines also generate messages directed to agent action processing 711. At educationally significant points during materials presentation, notations in the materials cause the engines to format a message to the agent. These messages also include  
15 an indication of event type and relevant data, perhaps including timing data. One student input can generate several agent messages. At points which are not educationally significant, the materials can not generate agent messages. Thus, the system can wait again for the next  
20 student action at wait point 707 if the previous student action had either no input significance for the materials or agent or no educational significance for the agent.

However, if messages have been sent to the agent, agent action processing 711 is activated. In the preferred but not  
25 limiting embodiment, this processing is table based. Rules from policy filter table 708 are evaluated in view of the data included in an incoming event message and in view of data on the student's past performance and the student's pedagogic model in student data object 712. For example,  
30 comparisons with student history are needed to determine relative performance. These rules propose candidate agent actions. Next, rules in decision weight table 709 and in selection criteria table 710 filter the proposed actions into a final list of agent actions. These final actions can cause  
35 the update of the information in student data object 712 with data on the student's current performance and behavior, as indicated by double headed arrow 728. They can also make

available control information for the materials, as indicated by arrow 725. Finally, and importantly, the actions can include display actions for causing visible agent behavior. The list of final display actions is sent to agent behavior processing 716. It is possible that no visible agent behavior is appropriate and that the list of display actions is empty. In this case the system waits for further student input actions at wait point 713.

Agent behavior processing 716 processes the final list of display actions communicated from agent action processing 711 in view of utterance tables 714, display behavior tables 715, preferences and the record of recent agent behavior in student data object 712 in order to generate a coherent display of the on-screen agent personae reacting to the previous actions. The final actions select utterance templates which are completed with parameters contained in the actions. The personae from the display behavior table selected according to the student preferences use these complete utterances to generate display objects, and perhaps animation scripts or applets, which are sent to the I/O facilities of the ES for final display 718. Agent behavior processing also updates the student data object with information concerning this current behavior.

Having completed all possible processing of the student input action, the system now waits at wait point 717 for the next student action or time interval.

#### 5.5. The Instructional Materials And The Tools

This section describes a preferred embodiment for the instructional materials, the student tools, and communications materials. In this embodiment, the materials have a uniform structure, being defined by materials data which is used by the materials engine to appropriately generate displays and perform functions. This uniform structure permits a uniform handling of the interface between all the materials and the agent. In alternative embodiments, certain tools and the group communication materials, for

example, can be advantageously separately implemented as separate programs that themselves maintain the necessary agent interface. Such certain tools include a calculator, a dictionary, an encyclopedia, and group communications. In 5 further alternative embodiments, each instructional material could be a separate program that also maintained the necessary agent interface.

This section first describes the general structure of the instructional materials and then describes the tools 10 typically available on an ABI system.

#### 5.5.1. The Instructional Materials

In a preferred embodiment a common materials engine interprets specific materials data to perform instructional 15 and tools functions. These are described with reference to instructional materials with adaptations needed for the other materials noted. Turning first to the materials data, in the preferred embodiment it includes three principal sections for presentation items, sequencing logic, and notations. The 20 presentation items include whatever is displayed, preferably represented as display objects, which can be parametrized. These display objects can be packaged with the materials data or can be downloaded from a server on demand. The notations contain additional data related to the materials display. 25 These include, for example, prerequisites, links to related material, expected student performance, and help and hints. The notations are preferably generated from templates referencing parameters from the materials data and student performance inputs. The materials engine uses notations to 30 generate messages to the agent, which comprise one part of the agent interface. The sequencing logic is executable or interpreted code that animates the particular materials. It references all data in the particular materials to cause the ordered display of the presentation items and to send 35 messages to the agent according to the notations.

The materials data is advantageously grouped into entries, each entry representing a minimum item of

presentation, which can, however, involve several screens. These entries are preferably specialized at least into a header or initialization entry and the other entries. Table 2A illustrates a typical materials header entry which is the first entry processed when the materials are initialized.

TABLE 2A: HEADER ENTRY

|    |                            |  |   |
|----|----------------------------|--|---|
| 10 | Instructional Header Entry |  |   |
|    | Presentation items         | Sequencing Logic   | Notations   |
| 15 |                            | Global variables;<br>Global functions;<br>Local variables;<br>Local functions; | Prerequisites for materials;<br>Reference to other materials or standard texts.   |
| 20 |                            |  | Agent initializing information including:<br>- meaning of global variables;<br>- education paradigm adopted<br>- available helps, tools |

This header has several particular features. The sequencing logic for the header frame consists largely of definitions of variables and functions. The global variables are shared between system components and include the control variables that the agent sets and that the sequencing logic references and tests in order to be guided by agent control. These variables, which comprise another part of the agent interface, for example, can control the time pacing of instruction, the new concept seeding rate, the density of new examples, the time pacing, or the difficulty of discriminations. Local variables are available to the sequencing logic during materials processing. Global functions are those global system functions that can be called by the sequencing logic. Also, dictionary lookup, spell checking, or encyclopedia lookup can be globally implemented and shared. In a Windows™ environment, the



global functions can be DLLs. Finally, local functions are available locally to the sequencing logic. For example, in a scientific calculator tool, computations can be local functions. For a further example, in instructional materials the local functions are available for checking user inputs for correctness, scoring quizzes, and so forth.

The notations in the header entry generate materials initialization messages to the agent. These messages inform the agent about these materials, about what global variables they respond to, about what helps, hints, and tools are useful, and importantly about the educational paradigm the materials use. Preferably, information about this paradigm is structured according to the instructional materials interface standard. See *infra*. The notations can also contain additional information, such as prerequisites for the whole materials and references to other materials and texts. Finally, the presentation item can be, for example, an introductory screen.

Table 2B illustrates a typical entry which is processed during regular materials presentation.

TABLE 2B: MATERIALS ENTRY

|              |  |   |   |
|--------------|--|---|---|
| 25           | Instructional Entry N  |   |   |
|              | Presentation items   | Sequencing Logic  | Notations   |
| 30<br><br>35 | Display objects, possibly including those for text, graphics, sound, animation, or video | Interpreted or executed control statements referencing variables, notations, and any student input, and causing display of display objects and execution of notations | Prerequisites for frame; Expected timing, and difficulty; Relation to other frames; Links to other materials and sources. Changes to agent initializing information; Student performance data; Student error data |

For this entry, the presentation items are those for the materials display. The sequencing logic causes this display in view of the variables and other information in the materials data and any student input. Finally, the notations  
5 result in agent messages reporting changes in any parameters set at initialization, student performance data, student errors, and other educationally significant information. The notations can also contain information specific to this frame, such as expected difficulty and timing.

10       Turning now to the materials engine, its first processing step is to request the executive software to download the requested materials data from the instructional materials server. It next processes the header entry, links to global variables and functions, and sends initialization  
15 event messages to the agent. When presentation begins, it interprets or calls for execution the sequencing logic on the first frame. From this frame it proceeds to activate other frames as directed by the sequencing logic. Lastly, when the materials processing ends, any termination messages as  
20 directed by the notations are sent to the agent and the materials are deleted from the client.

In a preferred embodiment, the materials are all implemented similarly. Most differences between the instructional materials, tools, and communication materials  
25 are in the presentation items and the sequencing logic, including different global and local entities. All materials are expected to have notations for generating agent messages that record materials initiation and termination and student performance and errors. Preferably this information is  
30 reported in a standardized manner according to an instructional materials interface standard. See *infra*.

#### 5.5.2. The Tools

The ABI system is adaptable to a wide range of necessary  
35 and optional student and teacher tools tailored to the students and the courses of instructions. In the case of elementary education, the following preferable tools include

certain general tools and the communication, or joint work, materials. In the case of commercial education, other tools can be preferable. The schedule/calendar tool participates in permitting access to materials according to student  
5 schedule and is preferably found in all embodiments.

The discussion in the section is directed to an implementation for elementary education. It is not limiting in the tools that can be used in an implementation.

10                                   5.5.2.1. The General Tools

The general tools are preferably present in a range of forms selected according to data in the student data object, including grade level, and teacher permissions. One general tool is a calculator, which can have forms varying from a  
15 simple four function calculator to a complex graphing calculator. Other general tools include language tools, such as a spelling checker, a thesaurus, a word pronouncer, an encyclopedia, and a dictionary. Different levels of each language tool can be provided suitable for different grade  
20 levels. In an alternative embodiment, the language tools can be integrated with a "starfish" tool, which allows the user to place the center of a "starfish" over a particular word, and then, by selecting the appropriate arm of the starfish to obtain the definition, a pronunciation of the word, a rhyming  
25 word, a synonym, or an antonym. Another general tool is a word processor, perhaps with a drawing mode which can be provided as a multi-level set of writing and drawing tools. The writing and drawing capabilities available to a student are selectable by the student or teacher. A last general  
30 tool is a link-maker, which offers exercises in various types of memorization, such as paired associates, serial learning, ordered serial learning, and mnemonics. Finally, additional tools can be added to an implementation to meet specific educational needs. For example for geography lessons a map  
35 tool can be added. For student projects, an encyclopedia tool and a network search tool can be added. The Study Buddies™ can provide instruction in operation of the tools

such as the use of keywords and operators. Specialized tools can be added for commercial or industrial training.

#### 5.5.2.2. File System Tool

5 A general tool preferable in many embodiments is a file system with student access. In many instances, including elementary education, full view of and access to the system provided file system can be a disadvantage. Consequently this invention contemplates, providing a file system front  
10 end, or file system tool, that limits the student's view of and access to the system file system. This particular tool is advantageously implemented as part of the session manager and not as a material. With that implementation, customized iconic file representations are managed as part of the system  
15 area of the display.

One embodiment of such a file system tool presents a four level file system organized into shelves of books, each of which has sections, the sections having pages. A book representing a directory of files is opened when a student  
20 user selects its icon. The student navigates around the directory book by selecting tabs or by moving page by page, by selecting nextpage, lastpage, or other buttons. The student interacts with selected pages, or files, of the book, possibly creating new pages and sections. The student can  
25 also close the book. For most needs of elementary purposes, a single shelf with a few prespecified books is adequate. More advanced students can be given permission to create and use multiple shelves with new books and to cut and paste pages and sections from book to book. A page of a book, a  
30 file, is preferably presented with the materials that process it. For example, user-created text or graphics pages appear with the word processor active. Homework and instruction pages appear with the appropriate materials.

### 5.5.2.3. The Scheduler/Calendar Tool

The schedule/calendar is an important tool and is preferably always present. It is accessed when the ABI system initiates materials to verify the student is permitted  
5 and scheduled for this material, and also invoked when the system terminates materials to schedule new materials. It is accessed as a global function by the agent in response to a meta-request from the student seeking scheduling assistance. Further, it can be directly accessed by the student using the  
10 calendar tool icon appearing on the student desktop. When accessed, this tool displays a calendar book to the student, viewable in several ways.

This section describes, first, the schedule/calendar data, and second, the schedule/calendar processing. The  
15 schedule/calendar data is a subtype of and contained in the student data object. Generally, this data includes the following fields for each scheduled student activity:

- Name of scheduled activity and optionally an identifying message;
- 20 Activity priority;
- Deadline date and time, or a definition of a perpetual activity, which has periodic requirements but no completion date;
- 25 Link to material for the activity which in turn can specify activity completion criteria; for activity of a single student this is typically a particular instructional material; for group work activity a list of the students for the group and other communication information can also be in the  
30 calendar entry;
- Activity characteristics, for example whether this was entered by the student or teacher and whether this is to be marked complete by the student or system;
- 35 Activity status, completion status and submission status of any required reports.

This exemplary data, sufficient to define a scheduled activity, can alternatively be entered by the teacher or by

the student. If entered by the teacher, it can be protected from modification by the student. Data entry is preferably assisted by a teacher tool with a suitable screen format. Optional activities can be entered by the student if the  
5 teacher permits.

The schedule/calendar tool can be directed by the teacher to permit the student a range of scheduling initiatives. These initiatives can range from permitting the student freedom to schedule materials as desired to requiring  
10 the schedule/calendar tool to enforce a fixed order of student activities. In a preferred embodiment this is accomplished by the teacher's specifying initiative parameters including a deadline date/time, D, and a criterion priority, P, in the student data object. The  
15 schedule/calendar then schedules automatically all tasks with deadline less than or equal to D and with priority level greater than or equal to P. By varying D and P with respect to scheduled tasks the teacher can achieve the specified range of initiatives.

20 Schedule/calendar processing can be invoked by the executive software, by the student, or by the agent. As previously described, at the beginning of a student session or after termination of the use of a particular material, the executive software invokes schedule/calendar tool, first, to  
25 mark the terminated task complete, and then, to reference the calendar data in view of the initiative parameters to find activities requiring scheduling. If this tool finds only one activity in the calendar requiring scheduling, this required activity is initiated. If multiple required activities are  
30 found, the tool can, alternately, initiate the required activity of highest priority or allow the student a choice of which required task to initiate. If there are no required activities, the schedule/calendar tool allows student selection of the next task via the session manager.

35 The schedule/calendar tool can be invoked by the student by selecting the schedule/calendar icon in the system area of the display. When so invoked, the tool displays the student

calendar and scheduled activities in various formats from a monthly overview to details of individual activities. If permitted, the student can enter optional items or mark items complete.

- 5       The schedule/calendar tool can also be invoked by the agent when it receives a student meta-request of the type "What do I do next?" The agent retrieves the required and scheduled activities from this tool and also determines an expected time to complete each task based on student
- 10 performance from the student data object and the average time required for each task from the materials header. In view of this combined information, the agent can present to the student an ordered list of activities scheduled according to their expected time to complete.

15

#### 5.5.2.4. Communications Tools and Group Work Materials

- In a preferred embodiment, the ABI system includes communication, or group work, materials integrated with the remainder of the system. As for other tools and materials,
- 20 access to communications materials is granted by the scheduler/calendar tool. Communication work groups are assigned and scheduled in students' calendars with calendar entries preferably including the group members names and other communication parameters. When these materials are
- 25 activated by the scheduler, the communication group is begun. Alternatively, students can spontaneously request the formation of a communication group by the selection of a communication material. The scheduler/calendar tool can permit group activation if the students have no other
- 30 required activities. Alternatively, each particular communication material can also have specific access controls preferably set by the teacher that control the types of communication permitted and with whom the communications is permitted.
- 35       In manner similar to other tools and materials, the communication materials have an agent interface. Upon activation, they send initialization event messages to the

agent specifying the global control variables they will be sensitive to, the educational paradigm adopted, and available hints, helps, and other communication parameters. In alternative embodiments, the instructional materials

5 interface standards include special categories for communication based work that enable the agent to control these materials with specificity. During communication work, these materials generate event messages at educationally significant points.

10       Thereby, communication materials are fully integrated into an ABI embodiment. Further, in a preferred embodiment, communication materials are implemented in a manner similar to other materials. First, each communication material has a particular communication task specific for that communication

15 material or form of group work. The communication task manages the network interface for that particular type of communication or group activity by using the network protocols provided by the OS and ES, and provides its communication functions as global functions for access

20 through an ABI system. Second, these functions are made available to the student in a manner similar to other materials through particular materials data that includes presentation items, sequencing logic referencing these global communication functions, and notations generating event

25 messages for the agent. In an alternative embodiment, the communication materials can be programs, independent of the materials engine and perhaps part of the associated communication task, which internally generate the necessary agent event messages. In either embodiment, communication

30 materials tasks can be written either in the ABI implementation languages, or in a special purpose communication scripting language.

The particular communication materials in a preferred embodiment provide forms of group work or communication

35 including e-mail or message exchange, linking student groups for joint work on materials, and structured joint work such



as contests with rules. Each of these forms of group work or communication is described in the remainder of this section.

A first form of group work implemented by communication materials is E-mail and newsgroups. These are useful for  
5 teachers to send information to their classes, such as schedule and materials changes and to communicate with absent students. Teachers can also exchange information with each other or obtain help for system and other issues. Students can use this form to obtain help and advice, especially from  
10 remote sources, communicate with their teachers, and share work or interests with other students. E-mail and newsgroups are easily incorporated as previously discussed. Then materials data is authored that grants access to these functions and generates appropriate agent event messages.

15 Student linking is another form of group work implemented by communication materials. Students in session at separate clients can link together for various exemplary activities including simply talking with each other by voice or text or for joint work on a particular material in which  
20 the students have either similar roles, as in developing a document using a word processor, or different roles, as in a simulation or game. Another activity of linked students includes group activities, in which position of participants within a virtual environment determines activity and role  
25 within activity. A final exemplary activity for linking student groups is moderated activity, in which participation is controlled by a special coordinating task that perhaps executes on a server system. An example of this latter activity is a spelling bee which is described in more detail  
30 subsequently.

In the preferred embodiment, student linking includes the following steps. The first step is identification of other students with whom a given student can link. The group can be defined by the teacher in the schedule/calendar entry  
35 for this activity, or alternatively, in a communication access control particular to this linked work activity. Second, links must be established between the students to be

linked. These links can be to a single server communication materials task that receives and distributes messages.

Third, local and global actions must be determined. Local actions are those that result in output visible only to the user taking the action. Global actions are those that result in output visible to all the students in the linked group. These global actions can include communicating each student's input to all linked students, sharing information among all linked students, jointly creating information by students in the linked group, and storing jointly created information. The fourth step in linking is orderly disconnection from the linked group.

Linking can be implemented in alternative fashions. In all implementations the communications tools and materials for linked activities are integrated with the other components of an ABI system in one of the ways previously described. A simple implementation is to provide on each student's screen an icon and a message area for each linked student. Alternatively, one or more shared materials areas can be provided. Communication can be distributed through a single server task to which all linked students connect. A more advanced implementation of linking employs software packages similar to multi-user dungeons ("MUDs"), which contain a collection of virtual shared traversable spaces (called "rooms") in which users can interact either with each other or with elements within the room. MUDs are especially preferable for student group work in which different students have different roles with access to different system capabilities. For example, one student can be a recorder, having write-access to the group's notebook, while another can be the database expert, having access to a body of relevant data. MUDs are also be useful for teachers, communicating with each other within 'rooms' each set aside for a specific topic and forming a dynamic newsgroup.

Another form of group work implemented by communication materials is structured linking. Important examples of structured linking in which the students have different or

structured roles are educational contests. Exemplary of such contests is a spelling bee, an exemplary embodiment of which is described herein. In this embodiment, the spelling bee is managed by a server communication materials task, called the  
5 server spelling bee task, which preferably is executed on a server system, which communicates with local spelling bee tasks on the involved students' client system. Generally, the server spelling bee task initiates a spelling bee by accumulating connections with students local spelling bee  
10 tasks, then mediates the spelling bee by controlling student actions, and provides for orderly termination of the spelling bee. The local spelling bee tasks provide the communication functions accessed or required by the spelling bee materials data, which are scheduled or selected to invoke spelling bee  
15 participation, on the client systems. These materials also send event messages to the agent and are controlled by the student's agent. Alternately, the local spelling bee tasks can be programmed to communicate with the agent and perform the spelling bee without materials data.

20 In more detail, the spelling bee tasks carry out the following steps. The spelling bee server task is started at a teacher's request or automatically by the system. A list of eligible students can be selected by the teacher or automatically determined by the server task based on data in  
25 the student data objects, including class membership and a stated interest in spelling bees. The spelling bee activity can be scheduled for each individual student by the teacher or selected by the student. If a student desires to enter the spelling bee, the local spelling bee task is started by  
30 the ES and a message is returned to the server. No response within a specified amount of time is taken as indicating a desire not to join. If a student's data object shows that this is the first time in a spelling bee, an instructional and warm-up sequence can be authorized for the student by the  
35 agent in the server task. If enough eligible students join the spelling bee, the server task continues, otherwise it sends a termination message to those who have joined and

terminates. Each local spelling bee task obtains space on the student display indicating the other players and their inputs. Next the spelling bee begins, and the server task broadcasts the word to be spelled selected from a graded word  
5 list and the name of user to spell the word. Each local task echoes the word sent, preferably by requesting the on-screen agent voice the words as utterances with an appropriate affect. The spelling bee materials inform the student's local agent of the student's progress and performance in the  
10 spelling bee materials. The server task accepts input from designated user's local task and broadcasts it. The server task judges and reports on correctness of completed responses and, if incorrect, eliminates the student from further spelling requests. As student leave the spelling bee, the  
15 server task is notified and sends messages to the local tasks of continuing players in order to update their workspaces. In each case the student preferences for further spelling bees are checked and preference data in the student data object is updated. When only one student remains, the server  
20 spelling bee task terminates the game and reports results.

#### 5.6. The Agent And The Agent Interface

The agent is an important component of this invention and is further described in this section with reference to  
25 the student data object, the agent interface, agent processing, and agent adaptivity. The agent comprises the student data object which contains data on the student's performance on the various materials and data on the student's pedagogic model. The student data object is  
30 referenced and updated by other components of the system, for example, for report generation and for student scheduling. Other system components preferably have an interface to the agent in order that the agent can control the materials and guide the student in a uniform manner. Agent processing is  
35 divided into two phases, agent action processing and agent behavior processing. Finally, agent adaptivity in the preferred and in alternative embodiments is described.

### 5.6.1. Student Data Object

One student data object is created for each student in the ABI system and is the only permanent repository of data concerning that student. The student data comprises fixed data defining the student as well as evolving data describing the student's interaction with the system, the latter including current and past performance and data defining the agent's view of the student. The student data object is stored on the server system and is the source on the server system for all teacher and administrative reports concerning that student. Elements of the student data object are fetched to a client system as required once its associated student logs on to that client and on that client serves to control the agent and provide for agent adaptivity.

Figs. 10A, 10B and 11 illustrate the structure and operation of the student data object. Figs. 10A and 10B conceptually illustrates an exemplary structure for student data object 1101. It is an object comprising structured student data 1102 and methods 1103 for accessing and updating the student data. Student data is divided into global data 1104, materials related data 1105, including tool related data 1106, current lesson data 1107, and log data 1108. Global data, that is all items meaningful across all ABI materials, includes such subtypes as system data, agent behavior preference data 1109, agent student model data 1110, and schedule data 1111. System data includes student identifiers, student passwords, access privileges, grade levels, class registrations, etc. Agent behavior preference data 1109 relates to the multi-modal behaviors generated by the agent and includes student defined preferences for these behaviors as well as a summary of past agent behaviors. Student preferences can include options relating to agent visual appearance - species, gender, dress, or perhaps, no visual appearance - and similar options relating to audio behavior and text production. The summary of past agent behaviors is used to aid in the selection of reasonably varied future multi-modal behaviors. Agent student model

data 1110 includes items modeling the student's persistent behavior which the agent uses to individualize its interactions with the student. Such data items can include material retention rate, hint effectiveness, and preferred  
5 rewards. Updates to this data object made as the ABI client interacts with the student provide for agent adaptivity to the student. Finally, schedule data 1111 relates to assignments scheduled by the teacher and unchangeable by the student and optional items scheduled by the student. Data  
10 for each schedule item can include due dates, reminder alarms, and priorities.

Each course in which the student is currently enrolled has a separate materials related data area 1105 for the materials providing instruction in this course. In an  
15 exemplary embodiment, this data subtype includes standard and criteria data, usually set by the school system, which include objectives and standards the student must meet in the particular course, milestone data establishing objectives already met by the student, data relating to the student's  
20 progress in the materials, data relating to the student's use of tools in the materials, and performance data. Progress data includes data necessary for the student to leave the materials and resume the materials at the prior point. Performance data 1112 relates to student's performance over  
25 several lessons in the materials and can include mean performance, weighted moving averages of performance, patterns of performance, use of hints, use of retries, and needed remediation. Using such performance data, for example, means and weighted moving averages, permits the  
30 agent to determine whether student performance is improving or declining. Tool data 1106 contains essentially similar but more abbreviated data about use of system tools such as the calculator, dictionary, and word processor. This data can only include milestones and performance information.  
35 The status of each lesson presented by instructional materials is accumulated in current lesson data 1107. This subtype is created upon lesson initiation and deleted upon

lesson completion. In an exemplary embodiment, it includes short term measures of performance - such as error rates, weighted moving averages of error rates, and the use of hints and retries - short term measures of time latency - such as  
5 time to complete lesson segments and weighted moving averages of such times - work areas in which the agent can store information particular to the instructional materials - such as parameters to use in forming multimedia presentations - and lesson coaching parameters 1113. The lesson coaching  
10 parameters are used by the agent to provide feedback to the instructional materials so that their presentation can be individualized according to student performance. These parameters are governed by the instructional modalities employed by the particular instructional materials and can  
15 include values such as the seeding rate of new concepts, time pacing of the presentation, the density of examples, and the ratio of reinforcement.

Finally, the student data object has links to student log 1108. The log stores all messages input to agent  
20 processing and all actions from agent behavior processing. It can be used to create detailed audits of student behavior and system responses, which can be of interest to instructional designers, in order to improve instructional materials, and to educational researchers, in order to  
25 develop new modalities of instruction. With its carefully partitioned and functionally defined interfaces, the ABI system is easily adaptable to new modalities of instruction as well as to merely installing new materials.

The student data object also includes one or more data  
30 updating methods and one or more data accessing methods. Exemplary updating method 1114 includes two components, triggering event type 1115 and action list 1116. When a component of agent processing updates the student data object, it sends a message to the object including an update  
35 event type and a list of relevant parameters. The updating methods are searched to find one with a triggering event type which matches the event type of the update event. The one or

more methods having matching event types are then executed by performing all the actions in the included action list using the parameters in the update event message. Each action uses the supplied parameters to update data elements in the

5 student data object. A plurality of actions is generally associated with each method because it is typical for one event to cause changes in several student model data elements. For example, an update event related to the use of a tool causes changes in the relevant tool data subtype as

10 well as the associated instructional material subtype. Further, when a lesson is completed, the methods executed appropriately summarize student data from the current lesson subtype into all the permanent data subtypes. At this point, parameters such as 'hint effectiveness' in the agent student

15 model data 1110 are also updated. The 'hint effectiveness' parameter is accessed for uses including agent decision weighting and teacher report generation. One of the methods associated with the event type 'end of lesson' updates the parameter 'hint effectiveness' in the following exemplary

20 manner. The performance parameter 1120 'use of hints' is accessed to determine if update is required. If hints were provided to the student, the 'current lesson log' 1108 is used in calculating the two components of the parameter 'hint effectiveness' - 'hint effectiveness-before-first-try' and

25 'hint effectiveness-after-first-try'. These two components each hold an array of values which are used to compute a weighted moving average. In an alternative embodiment, a more complex formulation of this parameter can be used to provide a more detailed analysis of hint effectiveness - each

30 of its two components can be separated into subcomponents corresponding to subject area, hint types and other instructionally useful measures. It is further preferable, for data elements comparing a particular student to class peers according to various measures be entered into the

35 student data object. This can be done by executing appropriate update methods on the server system where such



comparison data is available from reports generated from the student database including all the student data objects.

Fig. 11 is an exemplary illustration of how a typical student action update event updates the student data object.

5 Other update events include agent action update events.

Update message 1201 is sent 1206 to the student data object from a component of agent processing to cause student model update. The update event type is "exercise\_done" and exemplary associated parameters are as indicated at 1202. In

10 this case method 1203 with triggering event type

"exercise\_done" is executed by performing the four associated actions. The first action updates relevant data elements in tool data subtype 1106. The second action updates the log 1108, as is done for all events. The third action updates  
15 timing latency data elements 1205 in current lesson subtype 1107. Finally, the fourth action updates student performance data elements 1204 in current lesson subtype 1107.

Any component of the ABI system needing to determine the value of particular data element in the student data object  
20 does so by sending an inquiry message to the student data object requesting the desired data element. The inquiry method for that data element retrieves and then returns the desired value. Such inquiries are typically made by the agent on the student client system and by inquiry and report  
25 generating programs on the server systems.

#### 5.6.2. The Agent/Materials Interface

The structure of the interface between the agent and the materials is important in the ABI system. It permits a  
30 single agent to control a wide range of materials through which it guides a single student. The agent achieves this by advantageously maintaining a model of the student's pedagogic characteristics, which it references in diverse situations to determine its actions. This section, first, describes the  
35 general procedural structure of this interface, and second, describes the preferred model for the content of the interface. This preferred model is structured according to

the instructional material interface standard (herein called "IMIS")

Communications between the agent and the materials is bidirectional. Events containing parameters are sent to the agent by the materials at educationally significant occurrences. In response, the agent sets global parameters controlling the materials and returns messages confirming actions proposed by the materials. In circumstances in which the materials needs to coordinate displays with the agent, it communicates synchronously with the agent. For example, when the student requests help or a hint, the materials can need to synchronously obtain the agent's permission to offer the help or hint. In other circumstances, the materials can asynchronously send informational messages to the agent. Such asynchronous agent input and possible output can give the system the appearance of spontaneity.

The agent/materials interface can be implemented in any convenient manner in a given OS. For example, it can be built on explicit messaging, shared memory areas, procedure calls to a socket interface, or other technology.

The global parameters set by the agent and which control the materials are preferably state variables that the materials sequencing logic references in order to make educationally significant sequencing decisions. The meanings of state variables to which a particular material is sensitive can be established at materials initialization according to specifications in a header materials data entry. Examples of such variables range from simple flags, such as those controlling the availability of helps and hints, to more sophisticated parameters, such as those controlling the rate of new concept introduction, the density of examples, or the speed of discrimination exercises.

Communications from the materials to the agent are controlled by notations in the materials data. A notation includes an event type, parameters associated with the event, and the condition under which the event is constructed and sent. Notations are activated when they are encountered in

sequencing logic in the materials data. There are two classes of notations, "point-wise" notations and "toggled" notations. Point-wise notations are evaluated exactly once when they are activated. Toggled notations are evaluated at 5 each input event following their activation until they are inactivated by a later notation.

Notations vary according to the materials. Some materials, such as simple e-mail, can contain no notations. Tool materials can contain notations indicating only correct 10 or incorrect use of the tool. Most instructional materials data contain several types of notations. Generally, the events generated by these notations send information similar to the following: number of retries, measures of rate in fluency drills, measures of performance such as percent 15 correct and the number of tries, partition of exercise items into similarity sets, and measures of the relative difficulty of items.

Table 2C illustrates exemplary types of notations generated by typical instructional materials.

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TABLE 2C: TYPES OF NOTATIONS

|    | NOTATION TYPE                | WHEN GENERATED                                 | TYPICAL PARAMETERS   |
|----|------------------------------|--|--|
|    | <b>POINT-WISE NOTATIONS:</b> |  |  |
| 5  | Lesson initialization        | At start of lesson                             | Educational paradigm used; meanings of state variables                                     |
|    | Partial response             | At partial answer for a requested input item   | Correctness of user input, time required   |
| 10 | Full response                | At complete answer for a requesting input item | Name of exercise, difficulty, related exercises; correctness of user input, time required, |
|    | Help/hint request            | User request for help or hint                  | None   |
| 15 | End of lesson                | End of lesson                                  | Objectives satisfied by lesson; performance; time required                                 |
|    | Point                        | At an error                                    | Screen location that agent can highlight or move to  |
|    | Say                          | At an error                                    | Message that agent can produce   |
| 20 | <b>TOGGLED NOTATIONS:</b>    |  |  |
|    | Latency                      | No input event                                 | Elapsed time, expected type of input   |
|    | Inappropriate input          | Inappropriate inputs from student              | Number and type of inappropriate inputs  |

25

#### 5.6.2.1. The Agent/Materials Interface Standard

In order that the student's agent can act generally to provide student guidance and control material presentation in a manner individualized to the student's pedagogic characteristics, it is preferable that an embodiment of this invention use an instructional materials interface standard (herein called "IMIS"). According to IMIS, it is preferable that the detailed content generated by the notations and passed in messages to the agent be structured in a standard fashion according to the particular educational paradigm adopted by the materials and independent of the particular content of the materials. Further, it is preferable that the

materials adopt one of a limited and defined set of educational paradigms contemplated in the standard. Finally, it is further preferable that the rules referenced by the agent in its associated processing tables and performance data in the student data object be similarly structured. Thereby, IMIS provides the agent with a materials independent view of the student.

IMIS is not limited to a particular set of educational paradigms. Any standard set or sets of paradigms appropriate to the intended students can be adopted for the interface standard. It is preferable that the standards adopted be based on principles of educational psychology and sound educational practice. In the following, this invention is described according to an IMIS appropriate for elementary education. The paradigms described below are not limiting.

#### Exemplary educational paradigms

Exemplary educational paradigms, also known as modes of instruction, are listed in Table 3.

TABLE 3: EXEMPLARY EDUCATIONAL PARADIGMS

|                                   |
|-----------------------------------|
| Interactive tutorial              |
| Fluency exercise                  |
| Paired association exercise       |
| Discrimination formation exercise |
| Simulation exercise               |

Each of these educational paradigms is preferably handled differently by the agent in response to differing descriptive information and student performance data. For example, a sequence of correct responses in a fluency exercise is expected. On the other hand, a sequence of correct responses in a paired associates exercise can be worth while for the agent to comment on.

Exemplary paradigm classification

The exemplary embodiment of IMIS standardizes these educational paradigms according to three pieces of information: the instructional context, the instructional format, and most specifically, the subject area. Materials notations should preferably specify all pieces for maximum agent flexibility, although the ABI system is adaptable to the materials specifying any number or none. If none are specified, agent actions are independent of the educational paradigm.

The instructional context is the specific mode of instruction being presented to the student by the materials. Examples of instructional contexts are:

TABLE 4: EXEMPLARY INSTRUCTIONAL CONTEXTS

---

|    |                   |
|----|-------------------|
|    | Prerequisite      |
|    | Test              |
|    | Review            |
|    | Pretest           |
| 20 | New material      |
|    | Introduction      |
|    | Discrimination    |
|    | Review            |
|    | Practice          |
|    | Fluency exercise  |
|    | Review            |
| 25 | Unit mastery test |

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Within each instructional context, materials can adopt instructional formats, the second component of the IMIS specification. Examples of instructional formats are:

TABLE 5: EXEMPLARY INSTRUCTIONAL FORMATS

---

|    |                                   |
|----|-----------------------------------|
|    | Multiple Choice                   |
|    | Fill-in-the-blank                 |
|    | Unprompted                        |
| 5  | Selected from list                |
|    | Paired Associates                 |
|    | By letter                         |
|    | By dragging                       |
|    | By matching                       |
|    | Computations                      |
|    | Simulations                       |
| 10 | Identify parts of figures or text |
|    | Simulation games                  |

---

Finally, student performance should preferably be stored relative to the subject area being worked on, as necessary for course level reporting. Thus, the third component of the exemplary IMIS is the subject area, such as mathematics or reading.

#### Exemplary standardization of agent data

IMIS standardizes system tables and data relevant to agent action processing according to this triple of information -- instructional context, instructional format, subject area -- which characterize the education paradigm adopted by the materials. The following description discusses standardization of notations in the materials, standardization of data in the student data object, and standardization of the agent action processing tables.

Notations in the materials are standardized according to IMIS as follows. For a lesson, exercise, or item, each material adopts one of the standard set of educational paradigms, or modes of instruction. The parameters to be passed to the agent in an event message are determined by the instructional context and each instructional format of this paradigm.

The following table contains an exemplary sequence of notations for a "prerequisites review" education paradigm, and

the parameters relevant to agent action processing that each notation sends to the agent.

TABLE 6: EXEMPLARY NOTATIONS FOR PREREQUISITES REVIEW

|    |   |  |
|----|---|--|
| 5  |   |  |
|    | <u>Site of Notation</u>                   | <u>Data Sent to Agent</u>  |
|    | Instructional<br>Sequence Entry<br>Header | Context Type: Prerequisites Review<br>Unit Name: Selecting Gender Pronouns<br>Subject Area: Grammar<br>Average Time: 5 minutes<br>Number of Exercises: 8 |
| 10 |   |  |
|    | Exercise 1 Entry<br>Header                | Format Type: Multiple Choice<br>Number of Options: 2<br>Difficulty: 0.3<br>Hint: Available   |
| 15 |   |  |
|    | Exercise k Entry<br>Header                | Format Type: Fill in Blank<br>Subformat: Select from Words in<br>Previous Sentence<br>Difficulty: 0.5  |

- 20 An aspect of these notations is to provide information about the quality of the student response, which, in this example, is given by the *a priori* probability of a correct answer. For example, selecting the correct response from two choices has an *a priori* probability of 0.5 if the choice is made at
- 25 random. Filling in a blank correctly is less likely by chance, if no cuing is provided in the exercise.
- Advantageously, notations containing the parameters associated with a given instructional context and a given instructional format can be stored as templates in libraries.
- 30 Notations are available in these libraries to generate necessary messages at materials initialization and during materials processing. An instructional designer then need only consult these libraries to obtain the notations appropriate to the educational paradigm of the materials
- 35 being authored.



The standardization of the student data object according to this exemplary embodiment of IMIS for elementary education is simply achieved by storing student performance data according to instructional context, instructional format, and  
5 subject area. Thereby, these characteristics can be taken into account when comparing student pedagogic performance in general across subject matter areas.

The final component of IMIS standardization is that of the agent action processing tables, the policy filter table,  
10 the decision weight table, and the selection rules. Event messages from the materials inform the agent of current values for the instructional context and instructional format. Since these values are parameters available to evaluate the conditions and functions contained in these  
15 tables, these tables can be, in effect, segmented into parts each corresponding to a particular instructional context and instructional format. Since there is considerable overlap between the parts of these tables, the number of rules does not proliferate. The current subject area is also available  
20 to segment the tables in the cases of those subjects that can require special treatment by agent action processing. Further, the IMIS standardization permits a more systematic and effective use of the mechanism which the agent uses to set global variables in the materials. These variables  
25 facilitate adaptive adjustments of instructional parameters, such as seeding rate and amount of prompting. These variables can be more effectively set in view of the current educational paradigm as indicated by the current values of the instructional context and format. IMIS is also useful in  
30 providing information to the student in response to "Where am I?" inquiries. The system can use the information contained in the entities in the information triple to respond, "You are halfway through the drill and practice on fractions," for example.

35

### Alternative agent embodiment enabled by IMIS

In alternative embodiments of agent action processing, the segmenting of the policy filter table and decision weight table, which provides a simplified 'intelligent instructional agent' for each kind of instructional context, instructional format, can be augmented by other techniques from artificial intelligence. Thus, the customized rules and functions contained in the action table can be augmented software modules, which extend the agent and are constructed based on such techniques as production rules systems with rule propagation or neural nets. Such additional modules could, for example, find complex patterns of student error unanticipated by the instructional designer. As additional artificial intelligence methods are incorporated into the agent software, new materials notations can be added to the notation repertoire.

#### 5.6.3. Agent Action Processing

Agent processing is divided into agent action processing, which determines on-screen agent display actions in response to input events, and agent behavior processing, which transforms display actions into displays to the student. In a preferred embodiment, agent action processing is rule based and event driven, and agent behavior processing is table based. This and the succeeding section describe the preferred embodiments of these divisions of agent processing.

Fig. 8 illustrates in more detail agent action processing. This processing is activated when event messages 801, representing either input events sent from the I/O handlers or educationally meaningful messages from the materials, are sent to the agent software. It transforms the input event messages into lists of display actions that activate the agent display and also has the important side effects of updating student data object 806, as indicated by arrow 815, and of setting materials control parameters, as indicated by arrow 816. It is possible a particular input

event can generate all or none of these outputs and side effects.

Agent action processing proceeds through three steps: event filtering, candidate action weighting, and display  
5 action selection. In common, each of these steps references rules in an associated table of rules. These rules include relations, functions, and procedures, all of which reference input parameters. Input parameters can be any appropriate data carried in the input event message and any appropriate  
10 data stored in student data object 806. In particular, as indicated by arrow 815, fields from the following subtypes in the student data model are referenced: the current lesson subtype, the materials specific subtypes, and the agent pedagogic student model subtype. In alternative embodiments  
15 where the agent interface and data is structured according to an IMIS standard, event input parameters include parameters characterizing the current educational paradigm adopted by the materials. These parameters can be used to select rules applicable only to this paradigm for reference and  
20 activation.

Turning now to the steps of agent action processing, the first step is event filtering 807, referencing policy filter table 803. This step is described with reference to Table 7, an exemplary policy filter table.

25

30

35

TABLE 7: POLICY FILTER TABLE

| POLICY FILTER TABLE |  |
|---------------------|--|
| Active              | Rule   |
| 5 Y                 | $B(p_1, p_2, \dots, p_n), (type, subtype, x_1, x_2, \dots, x_n)$ |
|                     | -----  |
| Y                   | $(item\_diff > LIM), (congratulation, diff, 2, \dots)$           |
| Y                   | $(rate > f * average), (congratulation, rate, k, \dots)$         |
| 10 Y                | $(exercise\_done), (congratulation, done, r, t, \dots)$          |
|                     |  |
| N                   | $(latency > m), (hint, constructed, \dots)$                      |
| N                   | $((error\_rate < k) \& (WMA > MAX)), (remediation, review)$      |

- 15 The first row illustrates a generic policy filter rule, while subsequent rows illustrate exemplary filter rules. The generic rule has a condition and a consequent. The condition is boolean expression,  $B()$ , of one or more conditions,  $p_n$ , each of which is a function of the available parameters.
- 20 Default parameters in a rule can be overwritten by parameters from the input event. The consequent is a list of an agent action type, "type," an agent action subtype, "subtype," and zero or more parameters,  $x_n$ . The type is a major mode of agent behavior, for example, "congratulate the student," and
- 25 the subtype modifies that behavior, for example, "because of the student's rate." The parameters provide additional information to be used in constructing an utterance, for example the time that the student took to complete an item or the name of the item. Each rule can be marked active or
- 30 inactive, possibly as a result of selection during materials initialization or as a result of selection according to IMIS educational paradigm parameters. Processing a filter rule consists, first, in evaluating each active boolean, and second, for each such active and true expression, placing the
- 35 consequent and its parameters into the list of candidate actions. The list of candidate actions is then passed on to

action weighing 808, the next processing step. Also in the student data model, the current lesson subtype and materials specific data subtype are updated, if necessary, with data from the input event message. For example, upon item

5 completion, performance results need to be updated.

Action weighting 808 references decision weight table 804 and assigns a numeric weight to each action in the input candidate action list. This step is described with reference to Table 8 an exemplary decision weight table.

10

TABLE 8: DECISION WEIGHT TABLE

| DECISION WEIGHT TABLE |  |
|-----------------------|--|
| Active                | Rule   |
| Y                     | (type, subtype), weight_function( $x_1, x_2, \dots, x_n$ )   |
|                       | -----  |
| Y                     | (congratulation, diff), weight_function_j( $Y_1, Y_2, Y_3$ ) |
| Y                     | (congratulation, done), weight_function_k( $Z_1, Z_2$ )      |

20

The first row illustrates a generic policy filter rule, while subsequent rows illustrate exemplary filter rules. The generic rule has an index and a weight function. The index is a type and subtype pair, and the consequent is a weight

25 function of zero or more parameters,  $x_n$ , with a value between 0 and 1. Each rule can also be marked active or inactive, possibly as a result of selection during materials initialization or as a result of selection according to IMIS educational paradigm parameters. Processing the list of

30 candidate actions consists of, for each candidate action, selecting the weighting rules that have a type and a subtype matching that of the action and then assigning a relative priority between zero and one to the action as determined by applying the weight function to the available parameters. In

35 this manner all the candidate actions on the candidate action list are assigned a numerical weight. The list of weighted

candidate actions is then passed on to action selection 809, the last processing step.

Action selection 809 references selection criteria table 805 to select a final set of actions from the input candidate 5 action list. This step is described with reference to Table 9, an exemplary selection criteria table.

TABLE 9: SELECTION CRITERIA TABLE

|    |                          |                                       |
|----|--------------------------|---------------------------------------|
| 10 | SELECTION CRITERIA TABLE |                                       |
|    | Active                   | Rule                                  |
|    | N                        | (criterion)                           |
|    |                          | -----                                 |
| 15 | N                        | (use all actions with weight > MIN)   |
|    | Y                        | (use the most highly weighted action) |

The selection criteria table consists of a list of available methods for the candidate action selection process. A  
 20 selection criterion uses the computed weight and perhaps other parameters to select one or more final actions from the candidate weighted actions. Exemplary selection criteria are illustrated in the last two rows. It is anticipated that one  
 25 criteria is marked active as a result of selection during materials initialization or as a result of selection according to IMIS educational paradigm parameters. The active criteria is applied to select zero or more final actions. Some final actions are executed locally to provide control to the materials by setting control parameters, as  
 30 indicated by arrow 816. Other final actions can cause update of fields on the student data object, in particular in the agent pedagogic model subtype, as indicated by arrow 815. The remaining final actions are display actions which are passed to agent behavior processing in display action list  
 35 802. The student data object is updated to record the selected display actions.

Action processing is illustrated with reference to the exemplary rules in Tables 7, 8, and 9 by considering the results of processing two input events, one of type "item done" with a "difficulty greater than LIM" and one of type "exercise done." Applying the exemplary filter rules from Table 7 results in two candidate actions, one being (congratulation, diff) and the other being (congratulations, done). No other exemplary boolean expression evaluates to true. Next the exemplary weighting rules from Table 8 are simply applied by selecting and evaluating the correct weighting function. The resulting exemplary candidate action weights are taken to be 0.8 for (congratulation, diff) and 0.5 for (congratulations, done). Finally, the one active exemplary selection rule from Table 9 is applied which selects the one final action (congratulation, diff).

The preferred embodiment here illustrated involved no rule propagation. In alternative embodiments more sophisticated artificial intelligence programming techniques could be employed as is apparent to those of skill in the art. For example, rule propagation and general production rule systems could be used to transform events to actions. Other applicable techniques could involve neural nets, predicate logic, and so forth.

#### 5.6.4. Agent Behavior Processing

Agent behavior processing transforms display actions into output displays to the student. In a preferred embodiment, agent behavior processing selects from tables of possible display behaviors based on the input display action list and its parameters and on fields in the student data object describing student preferences and recent agent display behaviors. Further, in a preferred embodiment, agent behavior processing generates either display scripts which are sent to the I/O handler, or scripts with associated data snips of sound and animation that are embedded in applets. In alternative embodiments, intermediate scripts are not used and behavior processing generates I/O handler commands in

real time. This section describes agent behavior processing, first, with respect to the table data structures used, and second, with respect to the processing steps.

Generally, agent behavior processing includes two steps.

5 First, the message and its emotional affect, which is to be displayed or spoken by the on-screen agent, called herein the "utterance," is selected according to the input display actions. Second, the utterance and affect are sent to the preferred persona object where it is integrated into a

10 complete display, including animation, graphics and audio. The display is preferably represented as a script which is then sent to the I/O handlers. In behavior processing, the selected affect is an important parameter. The affect further characterizes the intent of the utterance. For

15 example, an utterance of a "congratulations" type is associated with a positive affect that can range from "happy," in cases of superior performance, to "encourage," in cases of improving but still less than average performance. The display behavior of the on-screen agent, preferably

20 represented as one or more personae interacting with each other and the student, is strongly responsive to the affect parameter. As is known in the arts of film animation, infusing an animation with an affect or emotion gives resulting images a human and life-like quality. Such a

25 quality is important so that the virtual tutor aspect of the ABI system engage the student in order to improve instructional results. Also, by storing recent affects selected in the student data objects, as well as student preferences for such parameters as affect intensity and

30 presentation, agent behavior processing can present a coherent and life-like image agreeable to the student over one instructional session or over several instructional sessions.

Affects are associated with and further characterize the

35 intent of utterances. They are selected as part of utterance generation processing for use in visual display generation processing. Utterance generation processing depends on the



type, subtype, and parameters of the current event as well as on the student data object, which contains the agent student model, student pedagogic parameters, and recently generated behaviors. Therefore, preferably, the selected affect and 5 generated visual displays are responsive to the student pedagogic characteristics or, alternatively, the student cognitive style.

Turning details of utterance generation, utterances and associated affect are generated by selecting options from a 10 hierarchy of tables. This hierarchy, having typically many choices for each level, provides variety in agent behavior. At the highest level of this hierarchy are the tables of utterance templates 908, which are indexed by action type and action subtype. Typically, there are many utterance 15 templates and associated affect for any given action type and subtype, and indexing is according to additional parameters that occur in action lists and additional parameters of student characteristics from the student data object. For example, utterances and affects are further selected 20 according to the educational paradigm employed, student grade level, and student preferences.

At the next level of the utterance generation hierarchy are tables of named slots, which are parametrized phrases, or in other words, functions which use input parameters to 25 return phrases. Utterance templates contain named slots as well as invariable words and sounds. When an utterance template is evaluated, slots with the specified name are selected from the slot table. Typically, there are many slots of a given name, which are further indexed according to 30 additional action list parameters and user characteristics from the student data object. When a slot is selected for use in the utterance template, slot parameters are passed from the utterance template. Alternative embodiments of this invention are adaptable to hierarchies with additional levels 35 of utterance generation tables or additional types of tables at a given level in the hierarchy.

Exemplary Table 10 is a small segment of the utterance template table for an action type of "congratulations" and an action subtype of "performance" and appropriate for a test type paradigm. Table 10 illustrates that the student grade 5 level, obtained from the student data object, is an additional indexing parameter for these utterance templates. Further, each illustrated template includes a slot named "performance-streak-slot," with parameters of grade level, number of problems answered correctly, and total number of 10 problems.

**TABLE 10: EXEMPLARY UTTERANCE TEMPLATES**

|    |   |
|----|---|
| 15 | (congratulations, performance, grade=4, "You got <performance-streak-slot(4, numright, total)> right.")                         |
|    | (congratulations, performance, grade=4, "You are really getting the hang of it.")   |
|    | (congratulations, performance, grade=8, "Quite a winning streak - <performance-streak-slot(8, numright, total)>.")              |
| 20 | (congratulations, performance, grade=12, "A stellar performance getting <performance-streak-slot(12, numright, total)> right.") |

It is preferable that the utterance template table have a large number of utterance templates appropriate to a large number of educational situations. Since the preferable number 25 of type and subtype combinations is at least approximately 500, and since it is preferable to have 10 to 100 responsive utterances per pair, a preferable utterance template table has at least 25,000 entries. A less preferable table has at least 5,000 entries and a more preferable table has at least 30 50,000 entries. In an embodiment of the invention, less used utterances have fewer candidate responsive utterances without impairing the image of system spontaneity. Thus this invention is adaptable to utterance tables of 1,000 entries.

Exemplary Table 11 is a small segment of the slot table 35 for slots named "performance-streak-slot," any of which could be employed in the previous templates. The illustrated slots

evaluate their input parameters to results in phrases. For example the last slot results in the phrase "90 percent" if numright is 9 and total is 10. Further, slots can contain a condition which controls their applicability. In this  
 5 example it is the fifth component of each entry and only the first slot has an non-null condition.

TABLE 11: EXEMPLARY SLOT ENTRIES

|    |   |
|----|---|
| 10 | (performance-streak-slot, 4-12, numright, total, <numright><br>> 0.8*<total>, "Nearly all") |
|    | (performance-streak-slot, 8-12, numright, total, nil,<br>"<numright> out of <total>")       |
|    | (performance-streak-slot, 8-12, numright, total, nil,<br>"100*<numright>/<total> percent")  |

15

Slots are used to create final, generated utterances with considerable variety. Therefore, it is preferable that the slot tables have at least the same number of entries as the utterance template table. A preferable slot has at least  
 20 25,000 entries. A less preferable table has at least 5,000 entries, and a more preferable table has at least 50,000 entries.

The final display of the preferred on-screen agent object is generated from Display Behavior Tables 904 with a  
 25 similar hierarchical table data structure to that used in utterance generation. At the highest level are on-screen agent actions which contain a cast of one or more personae. At the next level are persona types which the student selects once, or at most once per session. At the next level,  
 30 associated with each persona type is a library of display behaviors indexed by affect. Exemplary affect types include the following: sad, objective, pleased, happy, disappointed, announce, remind, encourage, reinforce, model, prompt, hint, joke, and tutor. Typically, each affect has many possible  
 35 behaviors and these are further indexed, as for utterance generation, by parameters appearing in the action list and the student data object. The display behaviors are

structured as scripts containing named display objects. These named display objects can optionally involve voice, audio, graphics, or video displays, and they are contained in scripts which can optionally specify a timed animated display or a branching display, where the branches are dependent on student reactions to the display. At the lowest level in the preferred embodiment are the individual named display objects. As for slots, typically there are several parametrized instantiations of each named object. These instantiations are indexed according to the same parameters indexing the display behaviors and in turn use these parameters to generate displays. Alternative embodiments of this invention are adaptable to hierarchies with additional levels of tables for display generation tables or additional types of tables at a given level in the hierarchy.

Exemplary Table 12 is a small segment with personae types adapted to elementary education.

TABLE 12: EXEMPLARY ON-SCREEN AGENT ACTIONS

|    |  |
|----|--|
| 20 | A frog persona writing the congratulatory message on a tiny blackboard, then jumping up and down croaking 'Hurray'.  |
|    | A robot persona creakily waving its arms and saying the congratulatory message.  |
| 25 | An animal persona wearing a cheerleader's outfit jumping up and down, chanting the congratulatory message as a cheer.  |
|    | The cat says the general part of the encouragement message while pointing to his bird sidekick. The bird then flies across the screen while saying the specific part of the message. |

It is preferable that the on-screen agent have a richly varied and engaging behavior. The persona types preferably include recognizable popular figures as well as a rich variety of specially created figures. Persona type tables have a preferable selection of at least 100, and less preferably at least 50 persona types. The libraries of display behaviors preferably have many behaviors for each affect. Since the preferable number of affects is at least

50, and since it is preferable to have 50 to 100 responsive behaviors per affect, a preferable behavior libraries have at least 2,500 entries, and more preferably 5,000 entries, per persona type. A fully implemented ABI system can have 5 preferable behavior libraries with approximately 125,000 entries. This number can be less in situations were more popular persona have fully configured behavior libraries while less popular persona have more limited libraries. Further, the number of persona types can be advantageously 10 limited to only the most popular or more appropriate for the type of student. Thus this invention is adaptable to libraries with approximately 1,000 entries of responsive behaviors.

In implementations of this invention, it is important 15 that the actual content of the utterance tables and the display tables and libraries be sufficiently creative and current to engage the student. Therefore, this content is preferably created by artists, animators, writers, and other creative talent. These elements of sound, voice, animation, 20 graphics and video are collected into libraries of data snips and stored in archives. Further, it is preferable that these tables have an extensive and varied content in order that agent displays repeat only infrequently.

Turning now to the process of generating a complete 25 agent display behavior, the steps of this process are described with reference to Fig. 9. The first step is utterance generation 906 which receives as input action list 901. Utterance generation indexes the utterance template table in accord with action list parameters, in particular 30 action type and subtype, and student preferences from the student data object, to obtain candidate utterance templates responsive to the current situation. If no candidates are found, the student preferences are relaxed in a preset order until at least one candidate is found. Typically, more than 35 one candidate is found, and then one template is selected at random from among those templates which have not yet been used previously in this session. A record of agent display

behavior during the session is stored in the student data object. The named slots of the selected template are resolved in a similar fashion, by finding candidate named slots and selecting one at random that has not been recently  
5 used. An utterance is then generated from the template, the named slot, and the input action list parameters. This utterance and its associated affect is passed to visual display generation.

The second step of agent behavior processing, visual  
10 display generation 907, uses the input utterance and associated affect to select candidate responsive displays of that affect from the libraries associated with the student's current persona(e) preference contained in the student data object 905. As with utterance generation, if no candidate is  
15 found, student preferences are relaxed until one is found. Typically, more than one is found, and one is selected randomly avoiding recent selections in this session. Display objects referenced in the selected display are similarly found. Finally, the utterance message is sent to the  
20 selected display and display objects. These objects contain performance methods that are called to generate and output display script. In a preferred embodiment, the script with references to data snips 909 of voice, sound, graphics, video and animation is incorporated into an applet. An exemplary  
25 applet can be a program fragment representing a character scratching his head while saying the utterance and moving across the screen. This output applet is sent to the I/O handlers in the ES for student display 908. Since this completes agent processing for this student or timer event,  
30 the system then waits for the next action at wait point 902.

A display action can also reference a preformatted animated sequence stored in the data snip library 909 in which voice, sound, graphics, animation and video have been already integrated. In this case, portions of utterance  
35 processing 906 and visual display processing 907 can be bypassed.

In alternative embodiments, selection of utterance or persona candidates from the available contents can be done other than randomly. For example, agent behavior data saved during a session in the student data object can be used to  
5 construct performances extending across instances of student actions. In particular, utterance templates and display objects can be selected in a connected manner in order to give agent display the appearance of continuity and realism. This invention is adaptable to other methods of generating  
10 performances parametrized by affect and utterance that are known in the art. These methods can include advanced text to speech techniques, 2-D and 3-D graphical generation, and VR effects.

The visualization of agent actions can involve a single  
15 character or several characters interacting with each other. If multiple characters are used, they are preferably interrelated. A typical cast is a cat with a bird sidekick. An exemplary interaction of these associated characters involving both dialogue and movement is presented in Table  
20 12.

Continuing story line scripts can be available from the ABI system on a daily basis in a manner similar to a continuing plot in a daily comic strip. These story lines can be applicable to a group of students and individualized  
25 where appropriate. In some cases the student's selected persona can introduce a story line and in other cases several personae are directly involved in an interaction. For example, the story line can be used as the basis for a reward such as "We're off to the beach to play volleyball. Join us  
30 when you finish your homework, then later help us solve the mystery of the vanishing lake."

In summary, the use of the student data object in agent behavior processing is illustrated in Table 13.

TABLE 13: STUDENT DATA USE IN AGENT BEHAVIOR

|    | STUDENT DATA  | EFFECTS   |
|----|---|---|
| 5  | Student persona choice  | Display persona, including type of character, voice inflection, activity rate, and so forth |
|    | Student's characteristics, including grade level, language ability, preferences, and so forth | Narrow candidate utterance template and candidate display                                   |
| 10 | Previous student interactions with materials or agent   | In alternative embodiments, utterance and display can relate to previous interactions       |
|    | Previous utterances in this session   | Selection of different utterance template and slots   |
| 15 | Previous displays in this session   | Selection of different display and display objects  |

Particular data in the student data object has an important role in determining agent display and insuring its  
 20 appropriateness, variety, and individualization.

#### 5.6.5. Agent Adaptivity

The adaptation of the agent to the student, and the ABI system's appearance as a virtual tutor, emerges from the  
 25 agent's updating of data in the student data object. In the preferred embodiment, the agent's knowledge of the student is represented by data in the student data object, in particular in the student pedagogic model, which stores general materials independent data describing how the student learns,  
 30 and in the materials specific student performance, which stores performance data specific to particular assigned materials and courses. As the student interacts with the system for instruction or homework, the agent receives event messages, which describe the student's learning and  
 35 performance. The agent updates the student data object with data from these messages. As this data is updated, the agent adapts to the student, and thereby the virtual tutor



individualizes to the student. This adaptation is maintained across sessions with this student.

In the preferred embodiment, the data referenced and updated by the agent are averages or weighted moving averages, giving more weight to recent than past behavior. Thus, the pedagogic model includes, for example, data weighted moving averages of the rates that the student learns discrimination of a certain complexity. Materials specific performance includes, for example, weighted moving averages of data on the student's response time and response latency.

In alternative implementations, agent adaptivity to its student can occur differently. In one alternative embodiment, student model data includes not only averages or weighted moving averages, but also data on the statistical distribution of the parameters involved, such as standard deviations. With this data the agent can recognize the current situation as "normal" or "abnormal" for this student and thereby offer appropriate guidance. Further, this statistical data can optionally include correlations between the agent data, such as between various pedagogic parameters and various materials parameters. In this manner, educational situations can be classified more finely than "normal" or "abnormal" into, for example, "abnormally slow on this fluency drill in view of normal progress on other exercises." In a further embodiment, classification of this statistical data can be done by special executable modules in the agent based on, for example, statistical classification schemes or neural networks.

In a further alternative embodiment, agent action processing can be implemented with more complicated techniques. In the preferred embodiment, agent action processing is done by rules without rule propagation. In alternative embodiments, rule propagation and full rule based systems can be used to transform events into actions. This invention is applicable to other techniques from artificial intelligence that can make this transformation such as Bayesian belief networks.

In another alternative embodiment, the student data object has data modeling student interests and preferences. Such a model enables the agent, for example, to monitor school events and suggest those appropriate to the user.

5 This model also enables the agent to provide rewards tailored to individual students, which enhances the system reinforcement and adds to perceived agent persona personality and to virtual tutor individualization. In a preferred embodiment, this model of student interests can be

10 implemented simply as a set of approximately 200 categories, covering interest in several subdivisions of each school subject area, as well as categories related to sports, leisure time and other areas of student interest. Interest in these categories can be entered in several manners.

15 Student use of the encyclopedia tool can be used to determine areas of current interest. Interest can be directly entered by the student, parent, or teacher. Alternately, student interest in materials can be inquired for when the materials terminate. After an assignment, the student could provide

20 semiotic feedback by selecting from a row of faces with different expressions. Alternately, the student can be quizzed on interests in a posed branching manner.

#### 6. SPECIFIC EMBODIMENTS, CITATION OF REFERENCES

25 The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and accompanying figures. Such

30 modifications are intended to fall within the scope of the appended claims.

Various publications are cited herein, the disclosures of which are incorporated by reference in their entireties.

## WHAT IS CLAIMED IS:

1. A method of operating an agent based instruction  
5 system for interactive instruction of a student over a  
plurality of instructional sessions, said method comprising:  
(a) presenting interactive instruction to said  
student by executing one or more materials on a computer  
accessed by said student for a current instructional session;  
10 (b) monitoring said interactive instruction of  
said student during said current instructional session;  
(c) storing information responsive to said  
monitoring of said student during said current instructional  
session for use during subsequent instructional sessions; and  
15 (d) outputting information on said computer to  
guide said student in said interactive instruction, said  
output information responsive to said monitoring of said  
student during said current instructional session and to said  
stored information responsive to said monitoring of said  
20 student during previous instructional sessions;  
whereby said system acts as a virtual tutor adapted  
to said student, said virtual tutor for guiding said  
interactive instruction of said student.

25 2. The method according to claim 1 further comprising  
after said step of monitoring a further step of controlling  
said one or more materials, said controlling responsive to  
said monitoring of said student during said current  
instructional session and to said stored information  
30 responsive to said monitoring of said student during previous  
instructional sessions, and wherein said one or more  
instructional materials are responsive to said controlling;  
whereby said interactive instruction presented by  
said system is individualized to said student.

35 3. The method according to claim 2 wherein said step  
of monitoring further comprises monitoring pedagogic

characteristics of said interactive instruction of said student by said one or more materials, and said step of controlling further comprises controlling said one or more materials in order to present interactive instruction with  
5 said pedagogic characteristics.

4. The method according to claim 3 wherein said pedagogic characteristics are selected from the group comprising time pacing of interactive instruction, new  
10 concept seeding rate, density of examples, and discrimination difficulty.

5. The method according to claim 2 wherein said step of monitoring further comprises monitoring according to an  
15 instructional context and an instructional format adopted by each of said one or more materials.

6. The method according to claim 2 further comprising before said step of controlling and said step of outputting a  
20 further step of generating at least one action responsive to said monitoring of said student during said current instructional session and to said stored information responsive to said monitoring of said student during previous instructional sessions, and wherein said step of controlling  
25 is responsive to said generated action(s) and wherein said step of outputting is responsive to said generated action(s).

7. The method according to claim 6 wherein said of generating step generates action(s) according to one or more  
30 tables of rules.

8. The method according to claim 6 wherein said of generating step generates action(s) according to one or more methods selected from the group of expert systems, neural  
35 networks, Bayesian belief networks, and statistical pattern recognition.

9. The method according to claim 1 wherein said step of outputting information further comprises (i) a step of selecting an utterance and an affect from one or more utterance tables in a manner responsive to said monitoring of said student during said current instructional session and to said stored information responsive to said monitoring of said student during previous instructional sessions, and (ii) a step of selecting a visual display from one or more tables of display behaviors in a manner responsive to said utterance, said affect, and said monitoring and said stored information.

10. The method according to claim 9 wherein said step of monitoring further comprises monitoring pedagogic information describing the pedagogic characteristics of said student, wherein said selected display behavior comprises one or more personae, and wherein said selected visual display is further responsive to said pedagogic information;

whereby said one or more personae present a life-like appearance individualized to said student's cognitive style.

11. The method according to claim 1 further comprising prior to said step of outputting a step of inputting at least one request of said student for guidance in said interactive instruction, and wherein said output information is further responsive to said input requests.

12. The method according to claim 1 wherein said computer accessed by said student is one computer of a plurality of computers interconnected by a network, and wherein said student can access any of said plurality of computers for an instructional session.

13. The method according to claim 1 wherein said output information further comprises an utterance, and wherein the step of outputting further comprises a step of selecting said

utterance from one or more candidate utterances, and a further step of outputting said utterance as text or speech.

14. The method according to claim 13 wherein said step  
5 of selecting further comprises selecting said one or more candidate utterance from one or more tables of utterances.

15. The method according to claim 14 wherein said one  
or more table of utterances comprise at least 1,000  
10 utterances.

16. The method according to claim 13 wherein said one  
or more candidate utterances comprises at least 10  
utterances.

15

17. The method according to claim 1 wherein said  
responsive output information further comprises a display  
behavior, and wherein the step of outputting further  
comprises a step of selecting said display behavior from one  
20 or more candidate display behaviors, and a further step of  
outputting said display behavior.

18. The method according to claim 17 wherein said step  
of selecting further comprises selecting one or more  
25 candidate display behaviors from one or more tables of  
display behaviors.

19. The method according to claim 18 wherein said one  
or more tables of display behaviors comprise at least 1,000  
30 display behaviors.

20. The method according to claim 17 wherein said one  
or more candidate display behaviors comprises at least 10  
display behaviors.

35

21. The method according to claim 17 wherein said step  
of outputting said selected display behavior comprises

outputting one or more modalities selected from the group consisting of text, voice, audio, animation, video, and preformatted animated sequences.

5        22. The method according to claim 17 wherein said selected display behavior comprises one or more persona.

23. The method according to claim 1 wherein said one or more materials is a plurality of materials.

10

24. The method according to claim 1 wherein said one or more students is a plurality of students.

25. The method according to claim 1 wherein said step  
15 of monitoring further comprises monitoring pedagogic information describing the pedagogic characteristics of said student in a manner independent of the subject matters of said one or more materials.

20        26. The method according to claim 1 wherein said step of monitoring further comprises monitoring progress and performance information describing the progress and performance of said student in said interactive instruction presented by each of said one or more materials.

25

27. The method according to claim 1 wherein said step of storing further comprises storing said information responsive to said monitoring in one of one or more student data objects, each student data object of said one or more  
30 student data objects being uniquely associated with exactly one student of said one or more students.

28. The method according to claim 1 wherein said one or more materials further comprise a material engine and one of  
35 more materials data, and wherein said step of presenting interactive instruction by executing one or more materials

further comprises executing said materials engine which references said one or more materials data.

29. The method according to claim 28 wherein said materials data further comprise notations, and wherein said step of monitoring further comprises said materials engine referencing said notations in order to generate monitoring information.

10 30. A method of operating an agent based instruction system for interactive instruction of one or more students, said method comprising:

(a) checking the authority of one of said students to access said system for interactive instruction by one or 15 more materials at a computer, said computer being one computer of a plurality of computers interconnected by a network;

(b) loading to said computer software and data for said interactive instruction;

20 (c) executing said one or more materials on said computer for presenting interactive instruction to said one student; and

(d) outputting information on said computer to guide said student in said interactive instruction, said 25 output information responsive to performance of said interactive instruction of said student.

31. The method according to claim 30 further comprising after said step of loading a further step of monitoring said 30 interactive instruction, said monitoring generating monitoring information that monitors said interactive instruction of said student, and wherein said step of outputting information is responsive to said monitoring information;

35 whereby said system acts as a virtual tutor adapted to said one student, said virtual tutor for guiding said interactive instruction of said student.



32. The method according to claim 31 further comprising after said monitoring step a further step of controlling said one or more materials to present instruction to said student that is responsive to said monitoring information, whereby  
5 said interactive instruction presented by said system is individualized to said student.

33. The method according to claim 32 further comprising after said loading step a further step of maintaining a model  
10 of said one student, said maintaining responsive to said monitoring information of said student, and wherein the step of outputting and the step of controlling are further responsive to said model of said student, whereby said  
outputting step and said controlling step adapt to said  
15 student thereby individualizing said interactive instruction of said student.

34. The method according to claim 30 wherein said one or more materials comprise a plurality of materials.

20

35. The method according to claim 30 wherein one or more of said plurality of computers are configured as one or more server computers for holding databases of software and data, and said step of loading further comprises loading  
25 across said network to said computer from said databases.

36. The method according to claim 35 wherein said loading occurs when said software and data is demanded at said computer.

30

37. The method according to claim 35 further comprising caching read-only data on said computer.

38. The method according to claim 30 wherein said step  
35 of outputting information further comprises outputting information in one or more output modalities.

39. The method according to claim 38 where said one or more output modalities are one or more output modalities selected from the group consisting of text, graphics, speech, audio, animation, video, and preformatted animated sequences.

5

40. The method according to claim 38 wherein said step of outputting selects said output modalities to output one or more persona or personae responsive to said interactive instruction.

10

41. The method according to claim 38 wherein said output modalities further comprise content, and said step of outputting information further comprises a step of loading said content to said computer.

15

42. A method of operating an agent based instruction system for interactive instruction of one or more students over a plurality of instructional sessions, said method comprising:

20

(a) presenting interactive instruction to one of said students by executing one or more materials on a computer accessed by said student for a current instructional session;

(b) monitoring said interactive instruction of  
25 said student during said current instructional session;

(c) storing information responsive to said monitoring of said student during said current instructional session for use during subsequent instructional sessions;

(d) determining an affect responsive to said  
30 monitoring of said student during said current instructional session and to said stored information responsive to said monitoring of said student during previous instructional sessions; and

(e) outputting information on said computer to  
35 guide said student in said interactive instruction, said output information responsive to said affect, to said monitoring of said student during said current instructional

session, and to said stored information responsive to said monitoring of said student during previous instructional sessions, said output information comprising a visual display;

5               whereby said visual display is responsive to said affect and to said interactive instruction in a life-like manner.

43. The method according to claim 42 wherein said step  
10 of monitoring further comprises monitoring pedagogic characteristics of said student, and wherein the step of determining an affect determines an affect further responsive to said pedagogic characteristics;

              whereby said visual display is responsive in a  
15 life-like manner individualized to said student's cognitive style.

44. The method according to claim 42 wherein said output information further comprises an utterance, and  
20 wherein the step of outputting further comprises a step of selecting said utterance from one or more tables of utterances in a manner responsive to said monitoring and to said stored information, and a further step of outputting said utterance as text or speech;

25               whereby said utterance and said visual display are responsive in a life-like manner.

45. The method according to claim 42 wherein said step of outputting further comprises selecting said visual display  
30 from one or more tables of visual displays in a manner responsive to said affect, to said monitoring, and to said stored information.

46. The method according to claim 42 wherein said  
35 selected display behavior comprises one or more persona.

47. An agent based instruction system for interactive instruction of one or more students, said system comprising:

(a) one or more computers having interactive input/output devices and interconnected by a network;

5 (b) one or more materials executable on said one or more computers, each said material for presenting interactive instruction to said one or more students and for generating monitoring information that monitors said interactive instruction; and

10 (c) one or more agents executable on said one or more computers, each said agent associated with exactly one of said students and each said student associated with exactly one of said agents, each said agent comprising

(i) action processing for controlling said  
15 one or more materials to instruct said associated student, said controlling being responsive to said monitoring information that monitors said interactive instruction of said associated student, and

(ii) behavior processing for outputting  
20 information to guide said associated student, said outputting being responsive to said monitoring information that monitors said interactive instruction of said associated student;

whereby said system acts as a virtual tutor to each of said students and said interactive instruction of each of  
25 said students is individualized to each student.

48. The system according to claim 47 further comprising executive software for interfacing said one or more materials and said one or more agents to said one or more computers and  
30 to said network.

49. The system according to claim 47 wherein said network is configured to permit any one of said students to access any one of said one or more materials from any one of  
35 said computers.

50. The system according to claim 47 wherein said network is configured to permit one or more of said computers to be located in one or more locations.

5 51. The system according to claim 50 wherein one or more of said locations are residences of one or more of said students.

52. The system according to claim 50 wherein one or  
10 more of said materials presents homework to one or more of said students.

53. The system according to claim 47 wherein said network is further configured to be a packet switched  
15 network.

54. The system according to claim 47 wherein said agent action processing is further responsive to a request for guidance from said associated student, and wherein said agent  
20 behavior processing is further responsive to said request for guidance.

55. The system according to claim 54 wherein said agent behavior processing further comprises (i) utterance  
25 generation processing for selecting an utterance and an affect responsive to said monitoring information or to said request for guidance, and (ii) visual display generation for selecting a visual display responsive to said utterance and said affect.

30

56. The system according to claim 55 wherein said agent behavior processing selects said utterance and said visual display to represent a persona, said selection being from a table of available personas and according to the preferences  
35 of said associated student.

57. The system according to claim 47 wherein said materials further comprise instructional materials executable on said computers for interactive instruction of said students, and tools executable on said computers for  
5 assistance of said students in said interactive instruction.

58. The system according to claim 57 wherein said instructional materials further comprise instructional materials appropriate to primary or secondary education.

10

59. The system according to claim 57 wherein said tools further comprise one or more tools selected from the group comprising a calculator, a dictionary, a thesaurus, an atlas, an encyclopedia, and a network search tool.

15

60. The system according to claim 57 wherein said tools further comprise a starfish tool for displaying and selecting relationships.

20

61. The system according to claim 47 further comprising one or more schedule/calendar tools executable on said computers, each said schedule/calendar tool associated with exactly one of said plurality of students and each said student associated with exactly one of said schedule/calendar  
25 tools, each said schedule/calendar tools for outputting to said associated student information relating to scheduled activities of said associated student, and for providing to said agent of said associated student information relating to scheduled activities of said associated student.

30

62. The system according to claim 61 further comprising data areas for each of said students characterizing scheduled activities according to deadline date and priority, and wherein said schedule/calendar tool further limits said  
35 associated student to interactive instruction according to said data areas characterizing said scheduled activities.

63. The system according to claim 47 further comprising one or more communication tools executable on said computers for providing forms of interactive group instruction to a group of said students, and for generating monitoring  
5 information that monitors said group instruction of each student in said group.

64. The system according to claim 63 where said forms of group instruction are selected from the group consisting  
10 of exchange of messages, group work on a shared material, and group participation in educational contests.

65. The system according to claim 47 wherein one or more of said materials further comprises materials engine  
15 software and materials data, and wherein said materials engine process said materials data to present said interactive instruction.

66. The system according to claim 65 wherein each of  
20 said materials data further comprises:

(a) a plurality of display objects for presentation;

(b) sequencing logic for controlling the order of said presentation of said plurality of display objects; and

25 (c) notations for causing generation of said monitoring information.

67. The system according to claim 47 wherein one or more of said materials comprises a program having data and  
30 instructions.

68. The system according to claim 47 further comprising pedagogic information data areas for each student, said pedagogic information data areas comprising data for a  
35 pedagogic model of said student, and wherein said agent action processing and said agent behavior processing is further responsive to said pedagogic information data areas.

69. The system according to claim 68 wherein said data in said pedagogic information data areas does not depend on the subject matter of said one or more materials.

5        70. The system according to claim 68 wherein said agent action processing updates said pedagogic information data areas associated with said agent's associated student, said updating being responsive to said monitoring information, whereby said associated agent adapts to said student.

10

71. The system according to claim 68 further comprising progress and performance data areas for each student, said progress and performance data areas comprising data describing progress and performance of each said student in  
15 said interactive instruction, and wherein said agent action processing and said agent behavior processing are further responsive to said progress and performance information data areas.

20        72. The system according to claim 71 wherein said agent action processing updates said progress and performance data areas associated with said associated student of said agent, said updating responsive to said monitoring information; whereby said associated agent adapts to said  
25 student.

73. The system according to claim 47 wherein one or more of said materials presents said interactive instruction according to an education paradigm, and wherein said  
30 monitoring information generated by said materials further comprises pedagogic information classified according to said education paradigm of said materials.

74. The system according to claim 73 further comprising  
35 control parameters for each material that have an educational paradigm, wherein each material presents said interactive instruction according to values of said control parameters,



and wherein said agent action processing assigns said values of said control parameters;

whereby said agent action processing controls said materials.

5

75. The system according to claim 73 wherein said educational paradigm is selected from the group consisting of interactive tutorial, fluency exercise, paired association exercise, discrimination formation exercise, and simulation  
10 exercise.

76. The system according to claim 73 wherein said educational paradigm is standardized according to an instructional context and an instructional format.

15

77. The system according to claim 76 wherein said instructional context is selected from the group consisting of prerequisite test, prerequisite review, pretest, new material introduction, new material discrimination, new  
20 material review, fluency exercise practice, review practice, and unit mastery test.

78. The system according to claim 76 wherein said instructional format is selected from the group consisting of  
25 multiple choice, unprompted fill-in-the-blank, fill-in-the-blank selected from a list, paired associates by letter, paired associates by dragging, paired associates by matching, computation, simulation to identify parts of figures or text, and simulation game.

30

79. The system according to claim 47 wherein said agent action processing generates at least one action responsive to said monitoring information.

35 80. The system according to claim 79 wherein said agent action processing further comprises software using one or more techniques selected from the group of expert systems,

neural networks, Bayesian belief networks, and statistical pattern recognition.

81. The system according to claim 79 further comprising  
5 a plurality of tables of rules, and wherein said agent action processing software further comprises software referencing said plurality of tables of rules in order to control said one or more materials and to generate said action(s).

10 82. The system according to claim 81 wherein said plurality of tables of rules comprises a policy filter table, a decision weight table, and a selection criteria table, and wherein said agent action processing references said policy filter table for determining one or more candidate actions,  
15 references said decision weight table for ranking said one or more candidate actions, and references said selection criteria table for selecting said action(s) from said ranked candidate actions.

20 83. The system according to claim 79 wherein said agent behavior processing is responsive to said action(s) in order to output information responsive to said monitoring information.

25 84. The system according to claim 83 further comprising a plurality of tables of possible outputs, and wherein said agent behavior processing software references said tables of possible outputs.

30 85. The system according to claim 84 wherein said one or more tables of possible outputs further comprise an utterance template table and a display behavior table, and wherein said agent behavior processing references said utterance template table for selecting an utterance and an  
35 affect according to said action(s), and references said display behavior table for selecting a visual display according to said action(s), said utterance, and said affect.

86. The system according to claim 83 wherein said agent behavior processing outputs information in a plurality of output modalities.

5        87. The system according to claim 83 wherein said output modalities are one or more output modalities selected from the group consisting of text, graphics, speech, audio, animation, video, and preformatted animated sequences.

10       88. The system according to claim 47 further comprising one or more student data objects, each of said student data objects associated with exactly one student, and wherein each agent stores information reflecting said monitoring  
information of said one student associated with said agent in  
15 said one student data object associated with said associated student.

89. The system according to claim 88 wherein said student data object associated with one student further  
20 comprises:

(a) pedagogic information describing a pedagogic model of said one student; and

(b) progress and performance information for describing the progress and performance of said student in  
25 said materials.

90. The system according to claim 89 wherein said agent associated with each student further comprises agent software and said student data object associated with said student,  
30 and wherein said agent software references and updates said associated student data object.

91. The system according to claim 47 wherein one or more of said computers are configured as server systems,  
35 wherein said server systems store said one or more materials and one or more agents, and wherein said one or more computers downloads said materials and said one or more

agents from said one or more server systems across said computer network.

92. The system according to claim 91 further comprising  
5 databases of pedagogic information and materials progress and performance information for said one or more students, and wherein said databases are stored on said server systems.

93. The system according to claim 92 further comprising  
10 reporting software for generating reports from said databases of pedagogic information and materials progress and performance information for said one or more students.

94. The system according to claim 47 further comprising  
15 one or more system managers executable on said one or more computers, wherein said interactive input/output devices include a computer display at each of said one or more computers, and wherein said system manager executing on one computer partitions said display of said one computer into  
20 one or more display areas.

95. The system according to claim 94 wherein said one or more display areas are selected from the group comprising an agent area for agent interactivity, a materials area for  
25 materials interactivity, and a system area in which said system manager displays selection icons for available system tools and facilities.

96. The system according to claim 95 wherein said one  
30 or more materials and said one or more agents provide facilities always available to said one or more students and said materials area and said agent area comprise sub-areas whose selection activates one of said always available facilities.

35

97. The system according to claim 95 wherein said one or more display areas change in size from time to time.

98. The system according to claim 47 wherein one or more teachers directs instruction of one or more of said students, said system further comprising:

- (a) one or more teacher materials executable on  
5 said one or more computers, each said teacher material for presenting interactive instruction to teachers in the use of said system and in the use of materials directed to said students and for generating monitoring information that monitors said interactive instruction; and
- 10 (b) one or more teacher agents executable on said one or more computers, each said teacher agent associated with exactly one of said teachers and each said teacher associated with exactly one of said agents, each said agent comprising
  - 15 (i) action processing for controlling said one or more materials to instruct said associated teacher, said controlling being responsive to said monitoring information that monitors said interactive instruction of said associated teacher, and
  - 20 (ii) behavior processing for outputting information to guide said associated teacher, said outputting being responsive to said monitoring information that monitors said interactive instruction of said associated teacher.

25 99. An agent based instruction system for interactive instruction of one or more students, said system comprising:

- (a) one or more computers having interactive input/output devices and interconnected by a network;
- (b) one or more materials executable on said one  
30 or more computers, each said material for presenting interactive instruction to said one or more students and for generating monitoring information that monitors said interactive instruction; and
- (c) one or more agents executable on said one or  
35 more computers, each said agent associated with exactly one of said students and each said student associated with exactly one of said agents, each said agent comprising

(i) utterance generation processing for selecting an affect and an utterance to guide said one associated student, said selecting of said affect and said utterance being responsive to said monitoring information  
5 that monitors said interactive instruction of said one associated student, and

(ii) visual display generation for selecting a visual display to guide said one associated student, said selecting of said visual display being responsive to said  
10 affect, to said utterance, and to said monitoring information that monitors said interactive instruction of said associated student, and

(iii) output processing for outputting to said associated student said selected utterance and said selected  
15 visual display;

whereby said selected visual display and said selected utterance are responsive to said affect and to said interactive instruction in a life-like manner.

20 100. The system according to claim 99 wherein said monitoring information further comprises pedagogic information describing the pedagogic characteristics of said associated student, and wherein utterance generation processing selects an affect further responsive to said  
25 pedagogic information;

whereby said selected visual display and said selected utterance are further responsive in a manner individualized to a cognitive style of said associated student.

30

101. The system according to claim 99 wherein said utterance generation processing selects said affect and said utterance from one or more tables of utterances.

35 102. The system according to claim 99 wherein said visual display processing selects said visual display from one or more tables of visual displays.

103. The system according to claim 99 wherein said selected visual display comprises one or more persona.

104. The system according to claim 99 further comprising  
5 action processing for generating at least one action and for controlling said one or more materials to instruct said associated student, said generating and said controlling being responsive to said monitoring information that monitors said interactive instruction of said associated student, and  
10 wherein said utterance generation processing and said visual display selection processing are further responsive to said action(s).

105. A method of operating an agent based instruction  
15 system for instruction of a plurality of students, said method comprising:

(a) executing one or more materials on a computer for presenting interactive instruction to one student of said plurality of students, said computer being one computer of a  
20 plurality of computers interconnected by a network, each computer of said plurality having interactive input/output devices;

(b) generating monitoring information that monitors said interactive instruction presented to said  
25 student; and

(c) controlling said one or more materials to instruct said student, said controlling being responsive to said information monitoring the interactive instruction of said student;

30 whereby said interactive instruction is individualized to each student of said plurality of students.

106. The method according to claim 105 further comprising after said step of generating a further step of  
35 outputting information on said computer to guide said student in said interactive instruction, said outputting information

responsive to said monitoring information of said interactive instruction of said student;

whereby said system acts as a virtual tutor adapted to said student, said virtual tutor for guiding said  
5 interactive instruction of said student.

107. The method according to claim ? wherein said output information further comprises one or more persona.

10 108. The method according to claim ? wherein said step of outputting information further comprises outputting information in a plurality of output modalities.

109. The method according to claim 108 wherein said  
15 output modalities are one or more output modalities selected from the group consisting of text, graphics, speech, audio, animation, video, and preformatted animated sequences

110. The method according to claim ? wherein said step  
20 of outputting information further comprises (i) a step of selecting an utterance and an affect from one or more utterance tables in a manner responsive to said controlling step and (ii) a step of selecting a visual display from one or more tables of display behaviors in a manner responsive to  
25 said utterance, said affect, and said controlling step.

111. The method according to claim ? further comprising prior to said outputting step a further step of inputting student requests for guidance in said interactive  
30 instruction, and wherein said step of outputting information is further responsive to said student requests.

112. The method according to claim 105 wherein said one or more materials is a plurality of materials.

35

113. The method according to claim 105 further comprising prior to said executing step a further step of



accessing any one of said computers by said one student, said accessing comprising verifying the authority of said one student to access said system for interactive instruction by said one or more materials.

5

114. The method according to claim 113 wherein one or more of said computers are located in a plurality of locations, and wherein the step of accessing further comprises accessing any of said computers in plurality of  
10 locations.

115. The method according to claim 114 wherein one or more of said plurality of locations are residences of one or more of said students, and wherein said one or more materials  
15 presents homework in said one or more residences.

116. The method according to claim 105 wherein said step of controlling further comprises controlling according to one or more tables of rules.

20

117. The method according to claim 116 wherein said one or more tables of rules further comprise a policy filter table, a decision weight table, and a selection criteria table, and wherein said controlling step controls said one or  
25 more materials according to one or more determined controlling actions, and wherein said controlling step references said policy filter table for determining one or more candidate controlling actions, references said decision weight table for ranking said one or more candidate  
30 controlling actions, and references said selection criteria table for selecting one or more controlling actions from said ranked candidate controlling actions.

118. The method according to claim 105 wherein said step  
35 of controlling further comprises controlling according to one or more methods selected from the group consisting of expert

systems, neural networks, Bayesian belief networks, and statistical pattern recognition.

119. The method according to claim 105 wherein the step  
5 of executing further comprises executing one or more of said one or more materials according to an educational paradigm, and wherein said monitoring information further comprises pedagogic information classified according to said educational paradigm adopted by said one or more materials.

10

120. The method according to claim 119 wherein said educational paradigm is standardized according to an instructional context and an instructional format.

15 121. The method according to claim 105 further comprising after said generating step a further step of updating one student model of a plurality of student models, each student of said plurality of students being associated with exactly one student model, said updating being  
20 responsive to the information monitoring the interactive instruction of said student, and wherein the step of controlling said one or more materials to instruct said student is further responsive to said student model of said student;

25 whereby said one or more materials are individualized to said student.

122. The method according to claim 121 wherein said step of updating further comprises updating pedagogic information  
30 in said student model, said pedagogic information describes pedagogic characteristics of said student of said plurality of students in a manner independent of the subject matters of said one or more materials.

35 123. The method according to claim 121 wherein said step of updating further comprises updating progress and performance information in said student model, said progress

and performance information describes the progress and performance of said student in said interactive instruction presented by each of said one or more materials.

5        124. The method according to claim 105 wherein said one or more materials further comprises one or more instructional materials for presenting interactive instruction to said plurality of students, and one or more tools for presenting interactive assistance to said plurality of students during  
10 said interactive instruction.

125. The method according to claim 105 further comprising prior to said controlling step (i) a step of executing one scheduler/calendar tools of a plurality of  
15 scheduler/calendar tools, each student of said plurality of students being associated with exactly one scheduler/calendar tool, said one scheduler/calendar tool providing said student with information relating to scheduled activities of said student, and (ii) a step of generating monitoring information  
20 that monitors said scheduled activities of said student.

126. The method according to claim 125 wherein the step of executing executes one or more materials that relate to said scheduled activities of said student.  
25

127. The method according to claim 105 further comprising prior to said controlling step (i) a step of executing one or more communication tools for presenting one or more forms of group instruction to a group of students,  
30 said group including said student, and (ii) a step of generating monitoring information that monitors said group instruction of said student.

128. A method of operating an agent based instruction  
35 system for instruction of a plurality of students, said method comprising:

(a) a step for executing one or more materials on a computer for presenting interactive instruction to each student, said computer being one computer of a plurality of computers interconnected by a network, each computer of said plurality having interactive input/output devices;

(b) a step for generating monitoring information that monitors said interactive instruction presented to each student of said plurality of students;

(c) a step for controlling said one or more materials to instruct each student, said controlling being responsive to said information monitoring the interactive instruction of each student; and

(d) a step of outputting information to each student in order to guide each student in said interactive instruction, said outputting step responsive to said information monitoring the interactive instruction of each student and responsive to said controlling step;

whereby said interactive instruction is individualized to each student of said plurality of students and acts as a virtual tutor individualized to each student.

129. An agent based instruction system for instruction of a plurality of students, said system comprising:

(a) means for presenting interactive instruction to each student by one or more materials;

(b) means for generating monitoring information that monitors said interactive instruction presented to each student;

(c) means for controlling said one or more materials to instruct each student, said controlling being responsive to said information monitoring the interactive instruction of each student; and

(d) means for outputting information to each student in order to guide each student in said interactive instruction, said means for outputting being responsive to said information monitoring the interactive instruction of each student and responsive to said means for controlling;

whereby said interactive instruction is individualized to each student and said acts as a virtual tutor individualized to each student.

5        130. An agent based instruction system for instruction of a student, said system comprising:

(a) one or more materials executable on a computer for presenting interactive instruction to said student, said computer having interactive input/output devices; and

10        (b) an agent executable on said computer, said agent (i) receiving monitoring information from each of said one or more materials that monitors said interactive instruction of said student, (ii) controlling said one or more materials to instruct said student, said controlling  
15 being responsive to said monitoring information, and (iii) outputting information to guide said student, said outputting being responsive to said monitoring information.

131. A system for agent-based, interactive instruction  
20 of one or more students over a plurality of instructional sessions, said system comprising:

(a) means for presenting interactive instruction to one of said students by executing one or more materials on a computer accessed by said student for a current  
25 instructional session;

(b) means for monitoring said interactive instruction of said student during said current instructional session;

(c) means for storing information responsive to  
30 said monitoring of said student during said current instructional session for use during subsequent instructional sessions; and

(d) means for outputting information on said computer to guide said student in said interactive  
35 instruction, said output information responsive to said monitoring of said student during said current instructional session and to said stored information responsive to said

monitoring of said student during previous instructional sessions;

whereby said system acts as a virtual tutor adapted to said student, said virtual tutor for guiding said  
5 interactive instruction of said student.

132. A system for agent-based, interactive instruction of one or more students over a plurality of instructional sessions, said system comprising:

10 (a) means for presenting interactive instruction to one of said students by executing one or more materials on a computer accessed by said student for a current instructional session;

(b) means for monitoring said interactive  
15 instruction of said student during said current instructional session;

(c) means for storing information responsive to said monitoring of said student during said current instructional session for use during subsequent instructional  
20 sessions;

(d) means for determining an affect responsive to said monitoring of said student during said current instructional session and to said stored information responsive to said monitoring of said student during previous  
25 instructional sessions; and

(e) means for outputting information on said computer to guide said student in said interactive instruction, said output information responsive to said affect, to said monitoring of said student during said  
30 current instructional session, and to said stored information responsive to said monitoring of said student during previous instructional sessions, said output information comprising a visual display;

whereby said visual display is responsive to said  
35 affect and to said interactive instruction in a life-like manner.

133. A computer readable medium comprising instructions for performing the method of claim 1.

134. A computer readable medium comprising instructions  
5 for performing the method of claim 30.

135. A computer readable medium comprising instructions for performing the method of claim 42.

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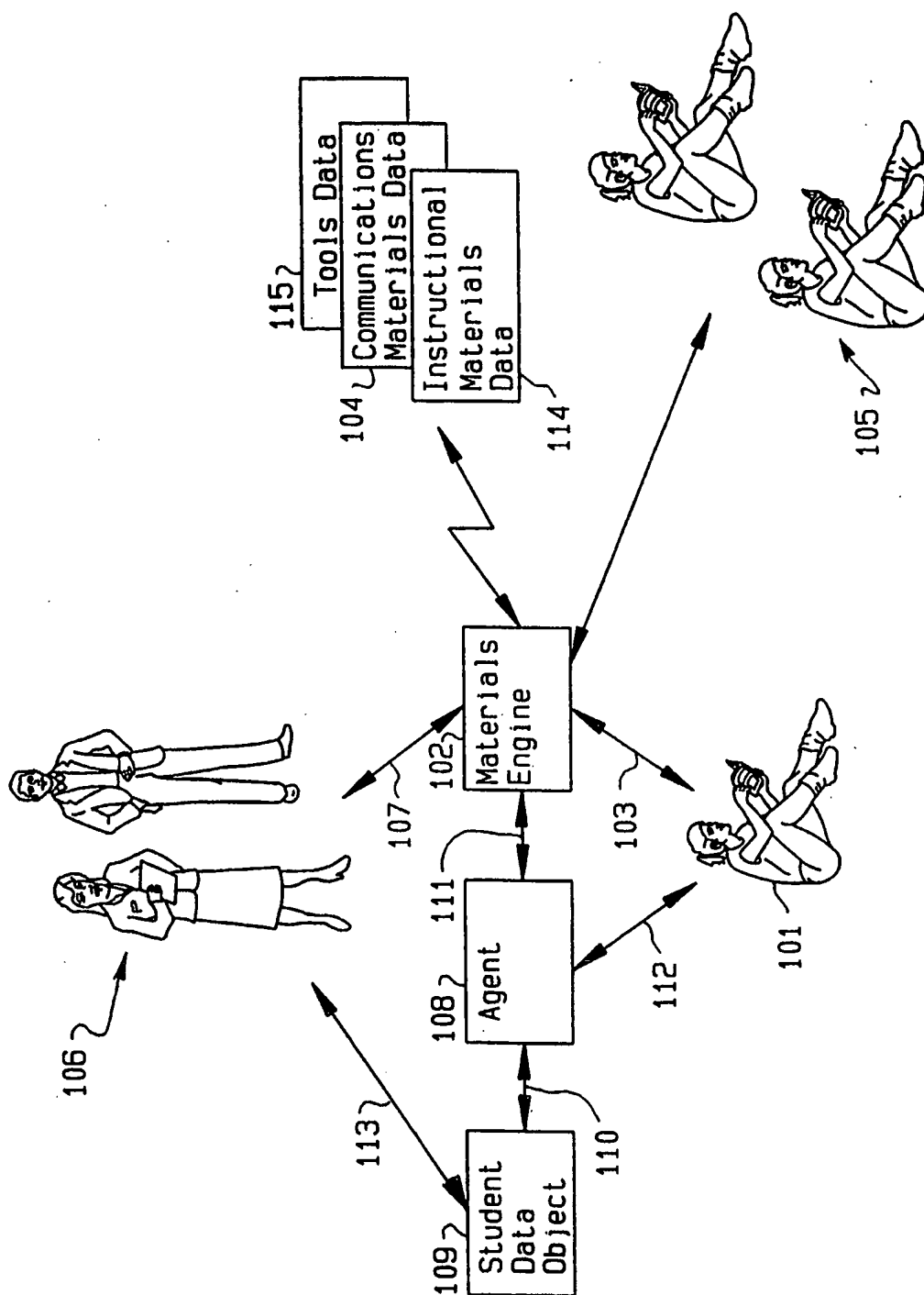


FIG. 1



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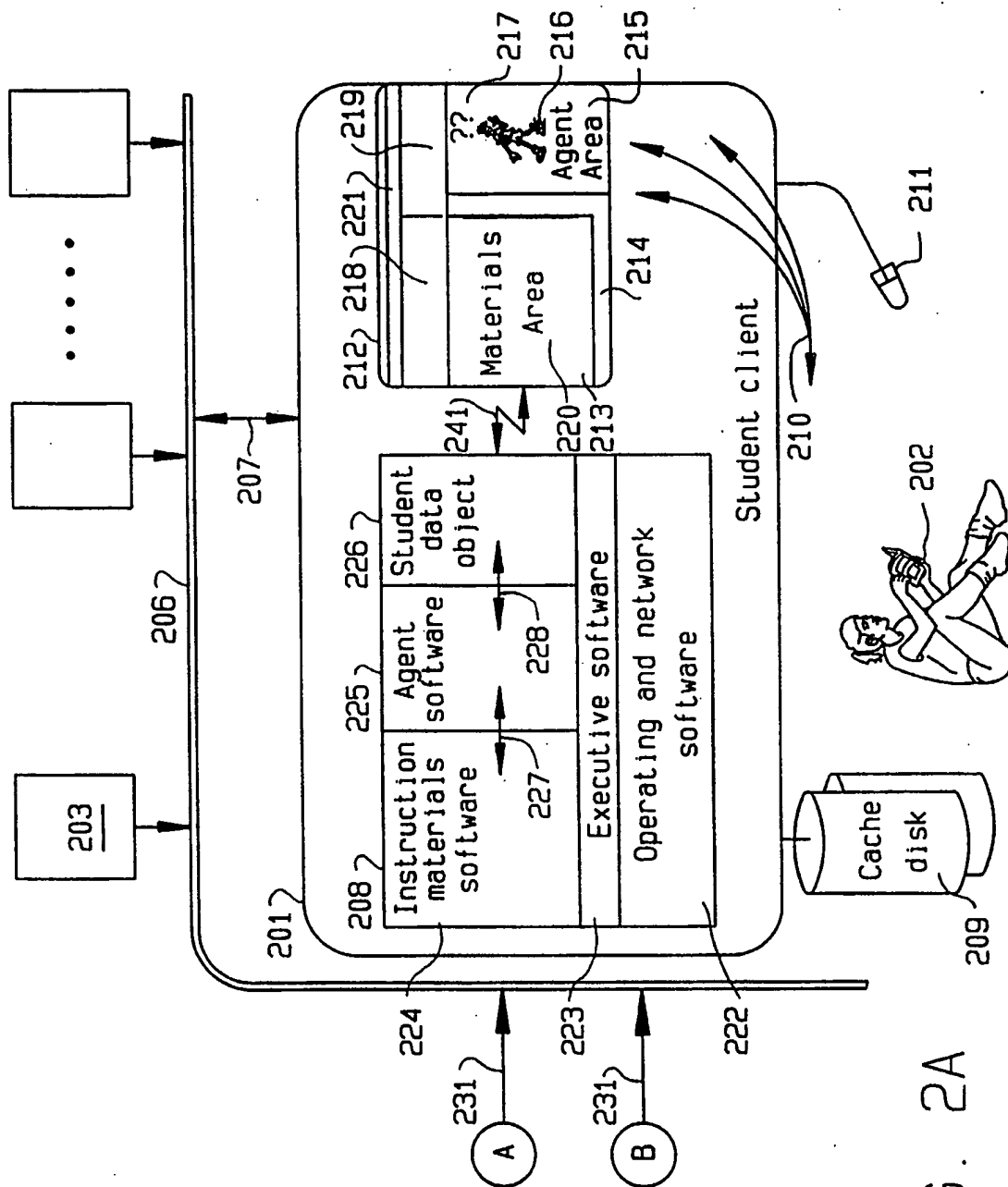


FIG. 2A

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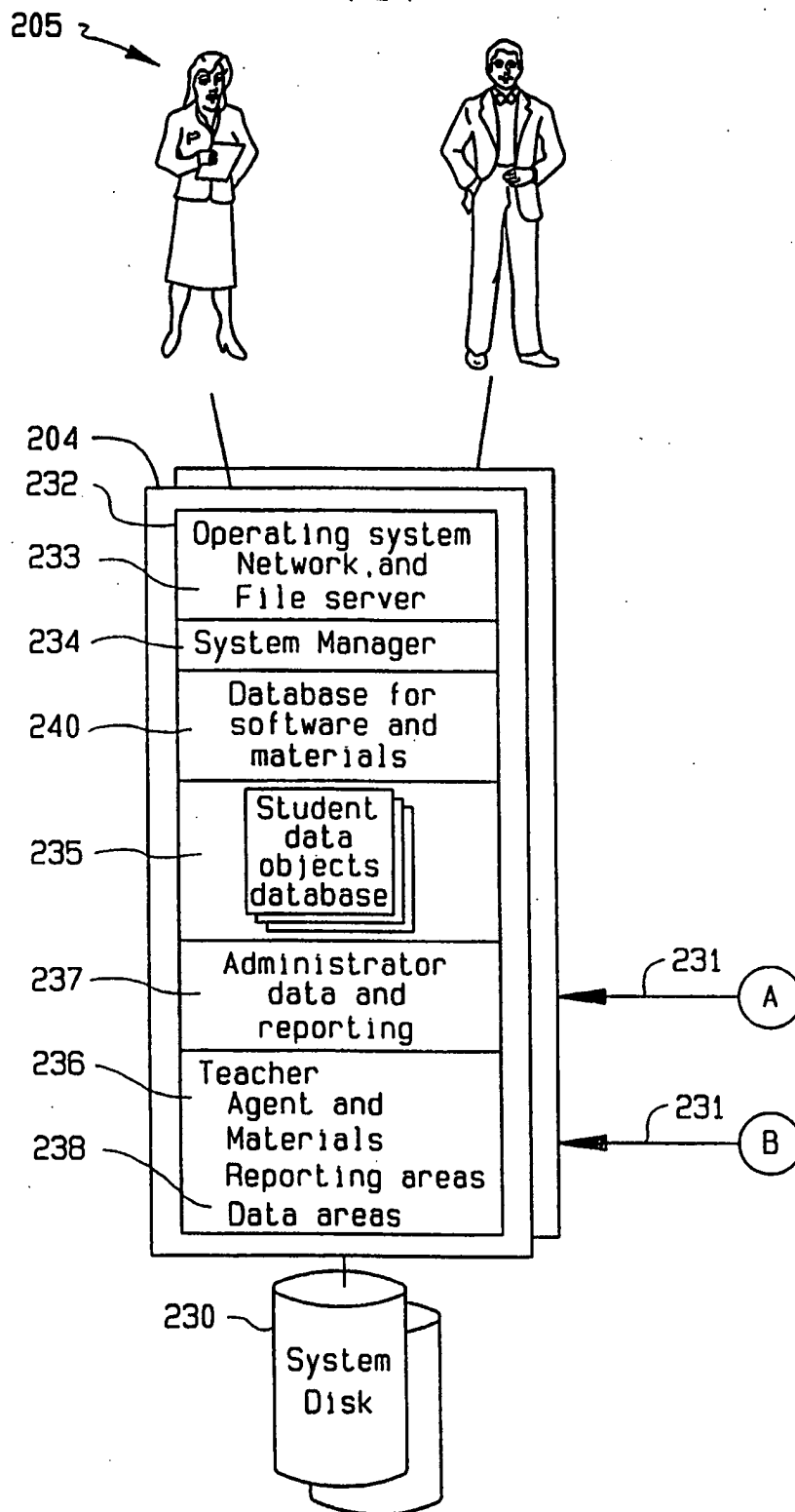


FIG. 2B

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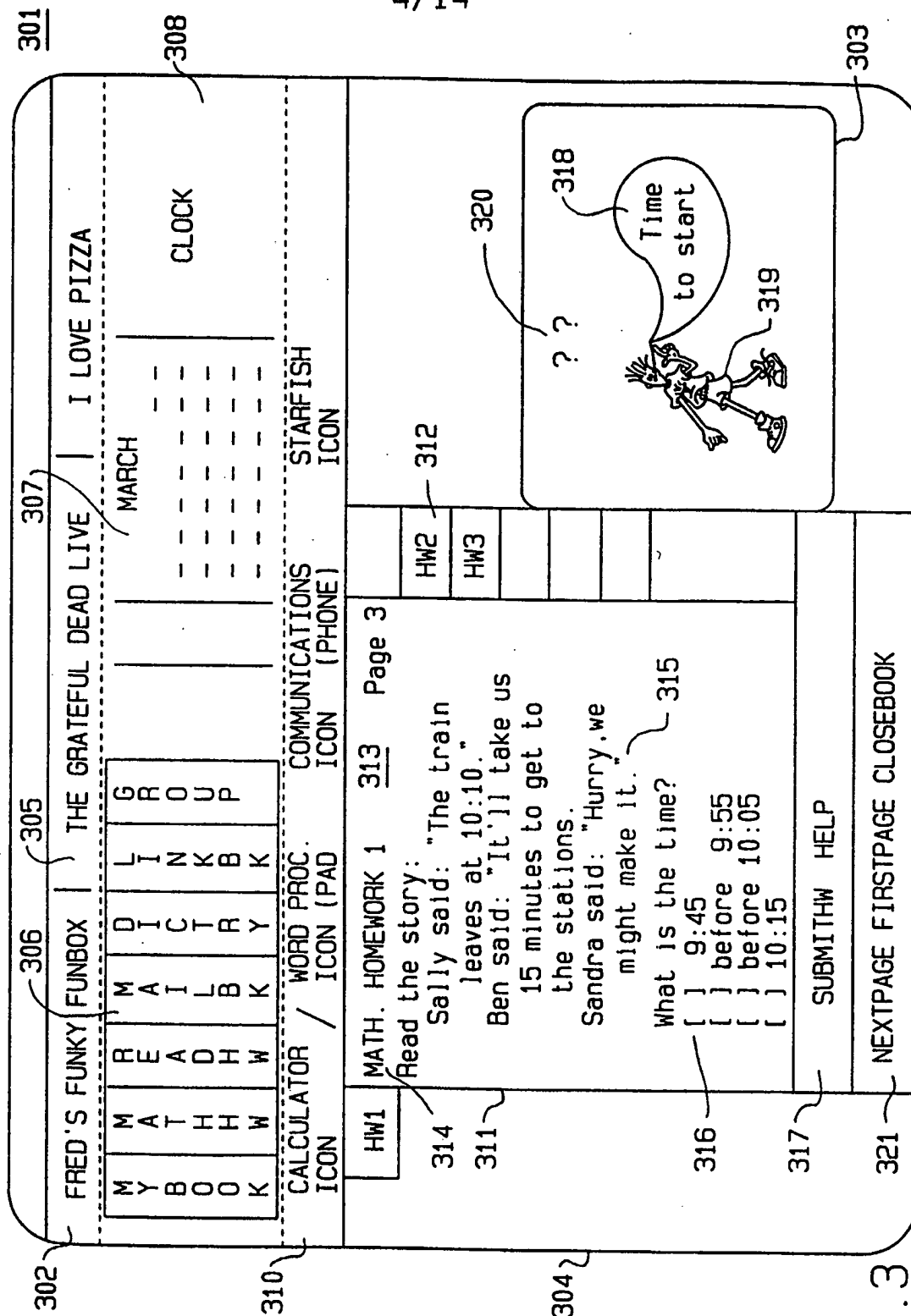


FIG. 3

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502
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**Exercise 11**

How do you solve

$\frac{4}{9} + \frac{3}{11} = ?$

$\frac{4}{9} + \frac{3}{11} = \frac{7}{20}$

$\frac{44}{99} + \frac{27}{99} = \frac{71}{99}$

$\frac{4}{9} + \frac{3}{11} = \frac{12}{99}$

$\frac{4}{9} + \frac{11}{3} = \frac{44}{27}$

" You left out an important step "

To add fractions, first you need common denominators.

☒

☐

☐

☐

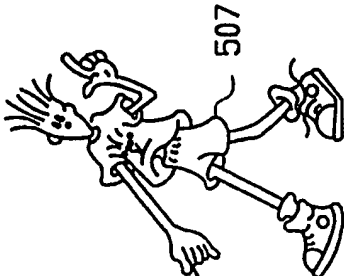


FIG. 4

SUBSTITUTE SHEET (RULE 26)

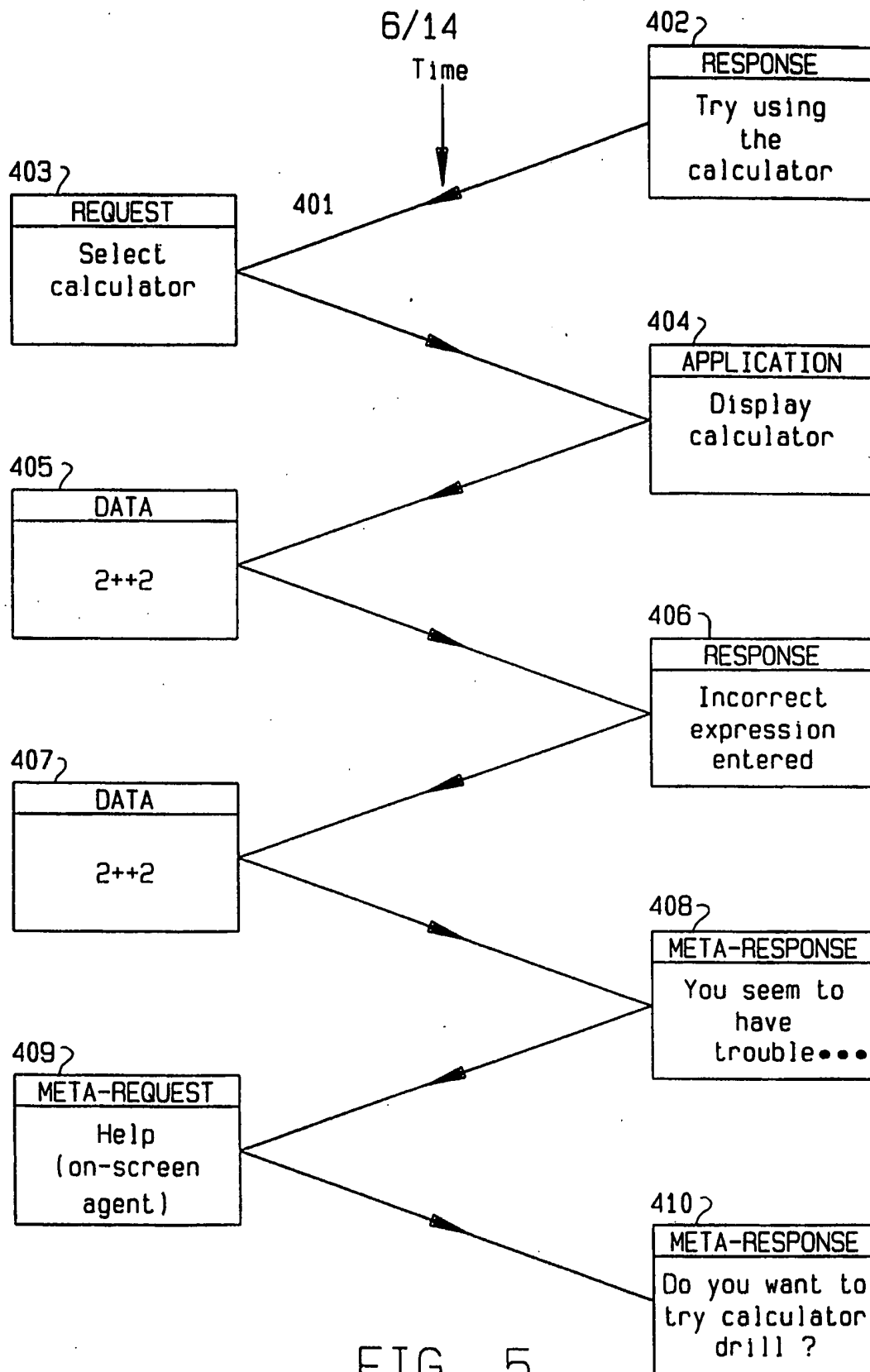


FIG. 5

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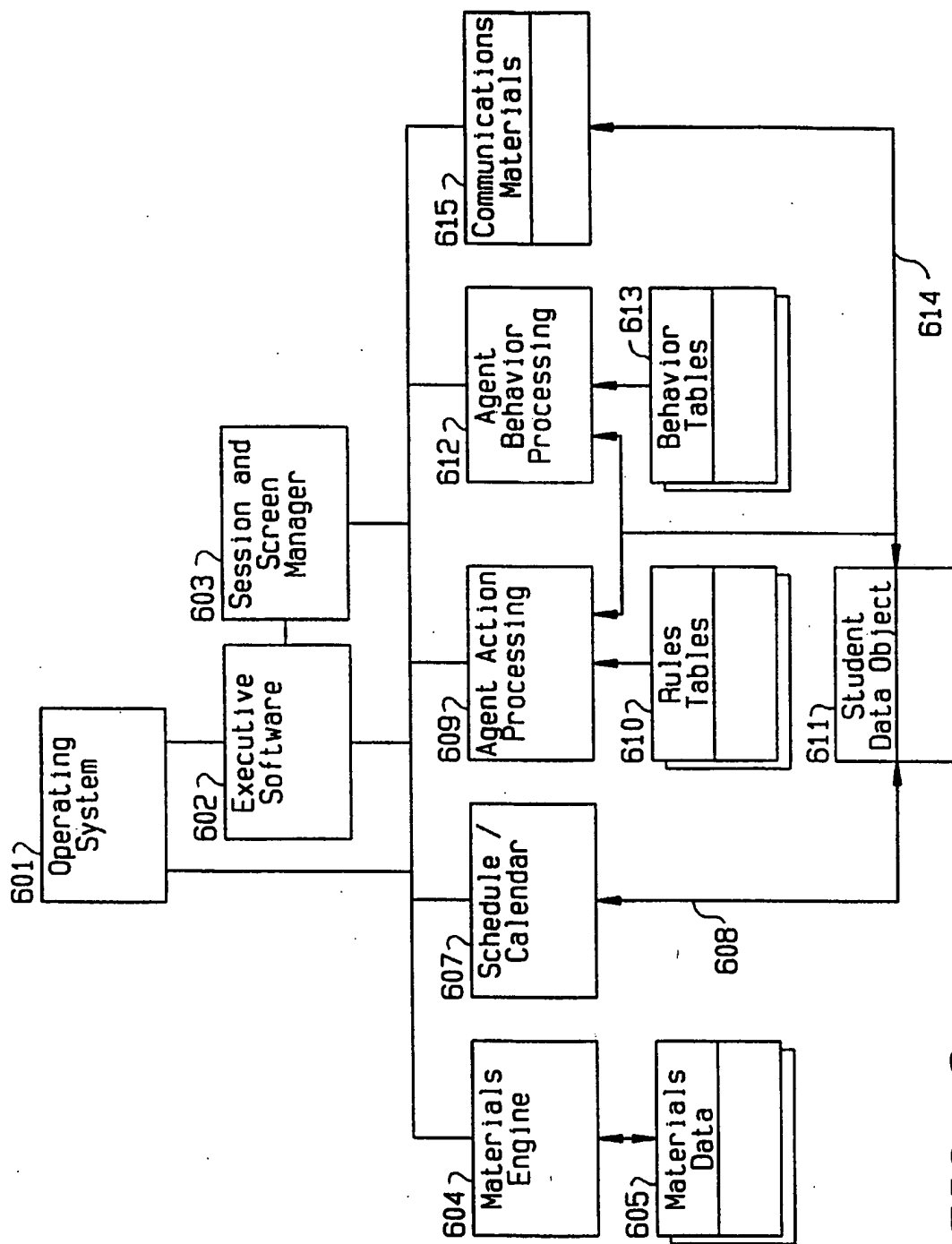


FIG. 6

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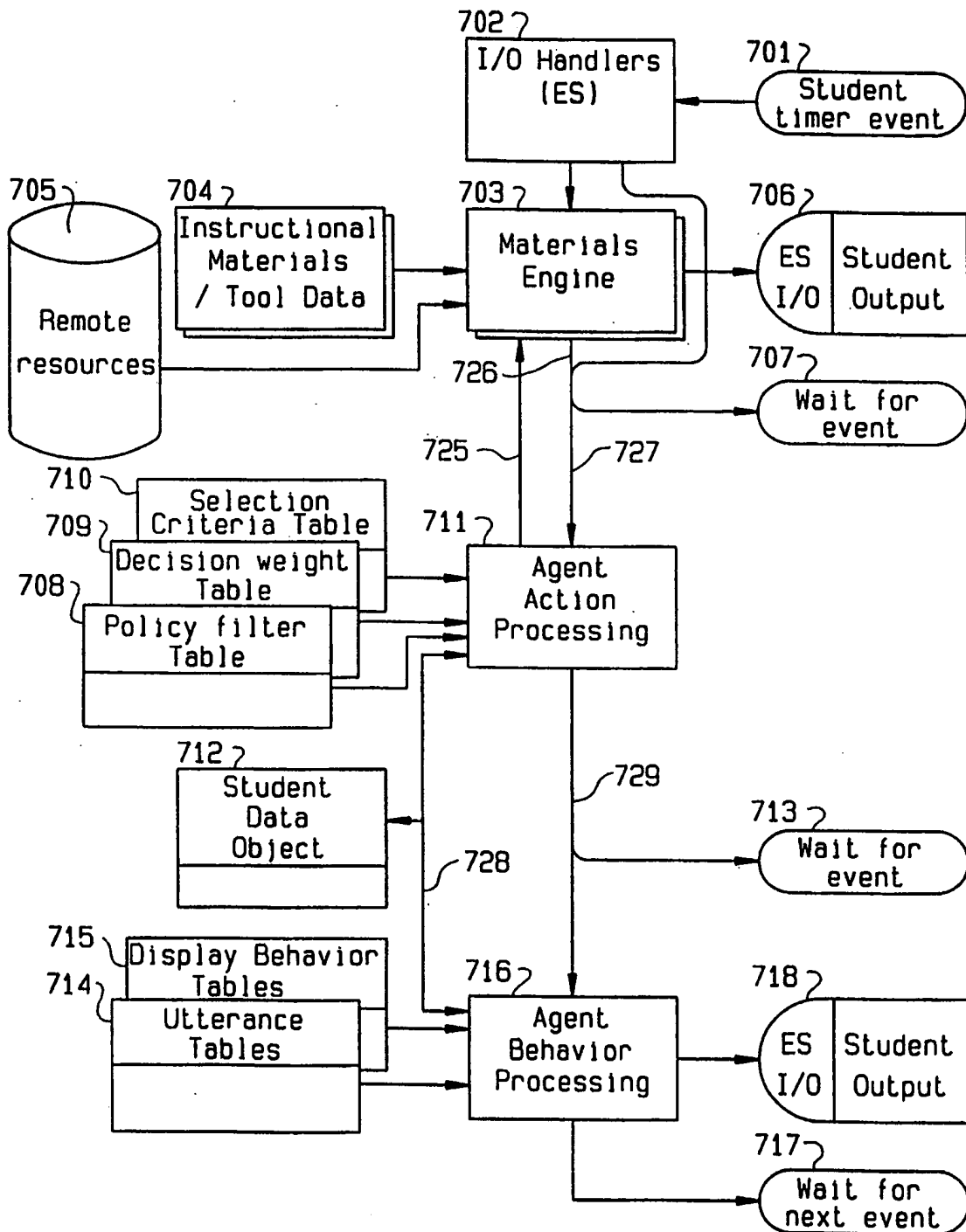


FIG. 7

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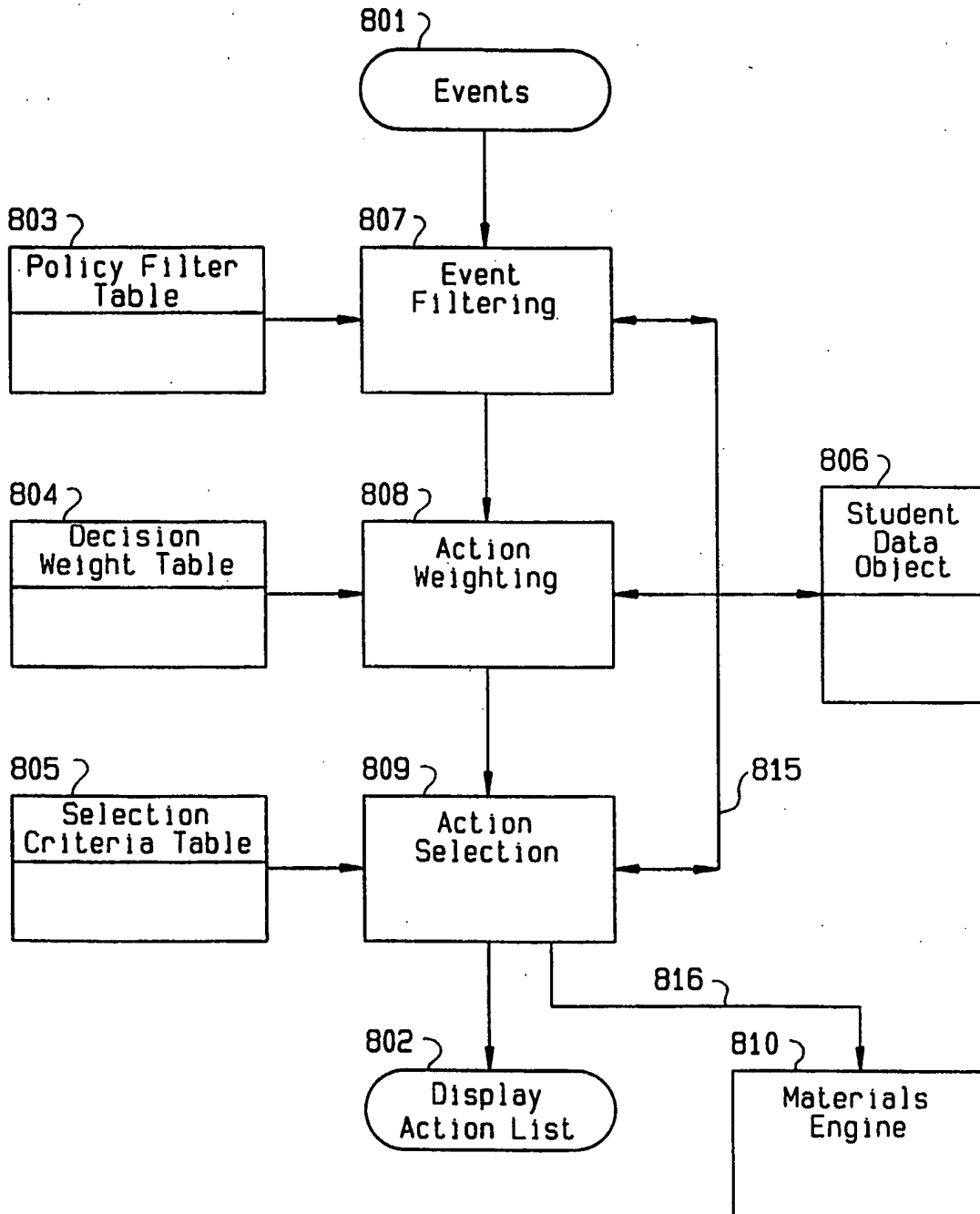


FIG. 8



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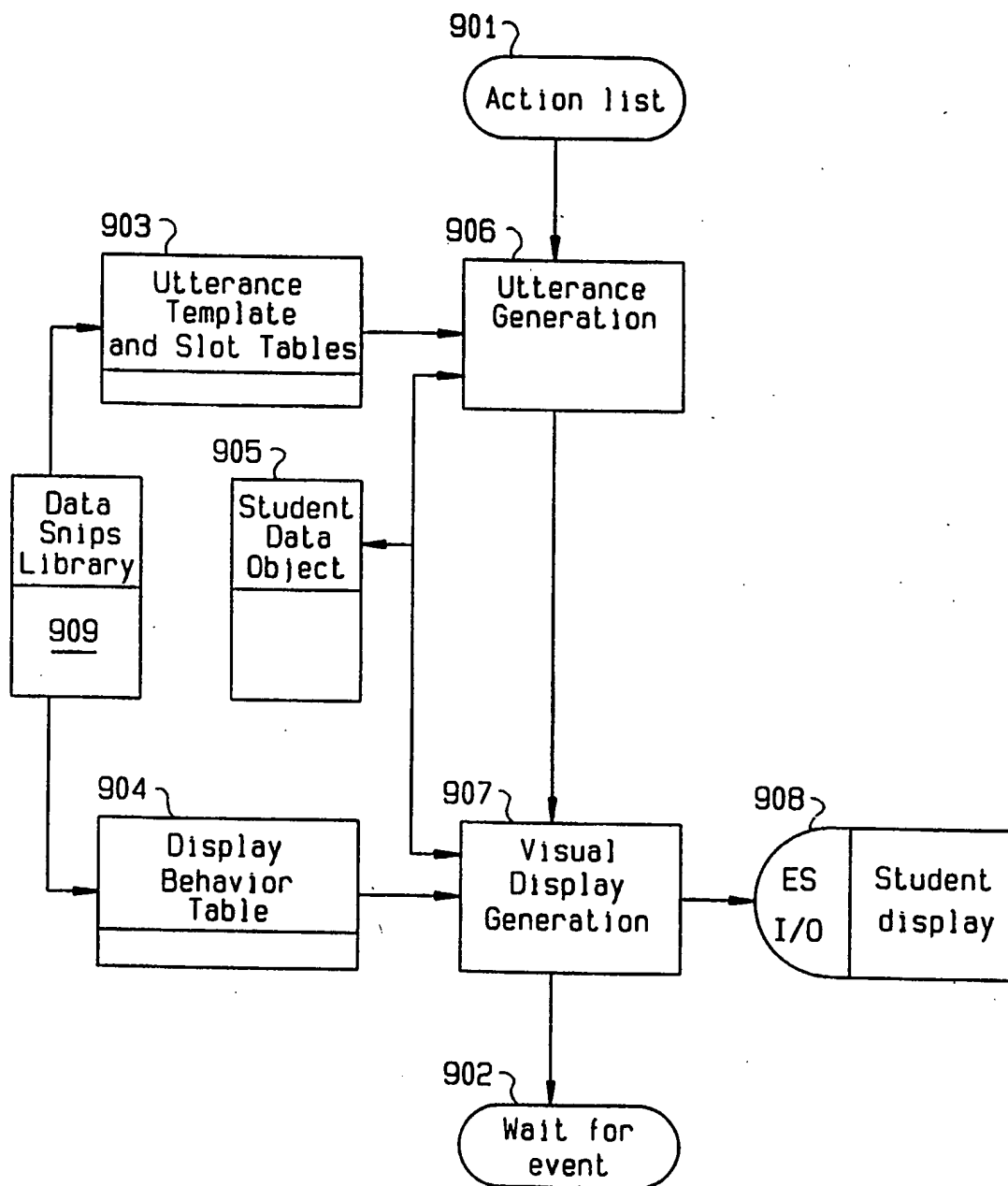


FIG. 9

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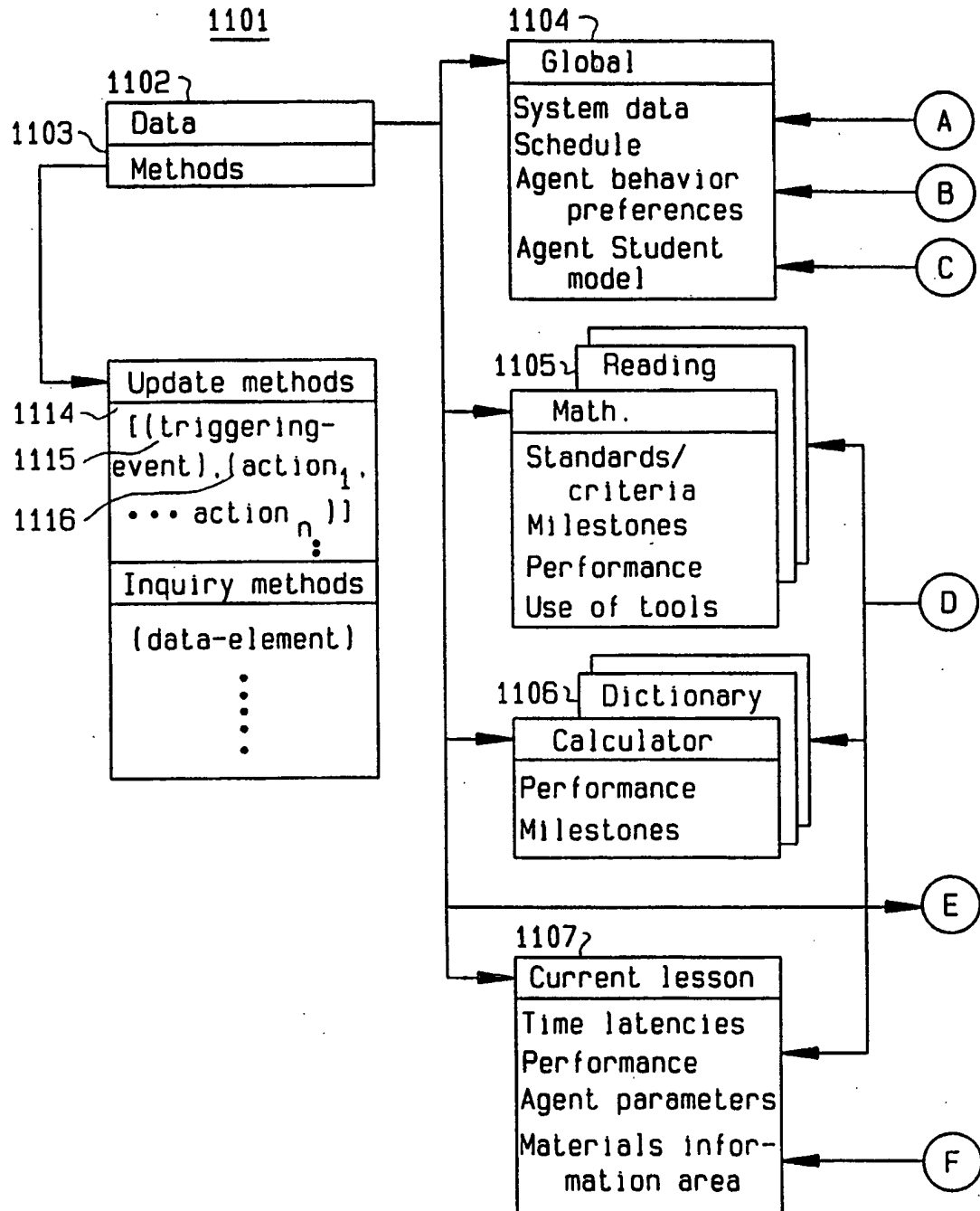


FIG. 10A

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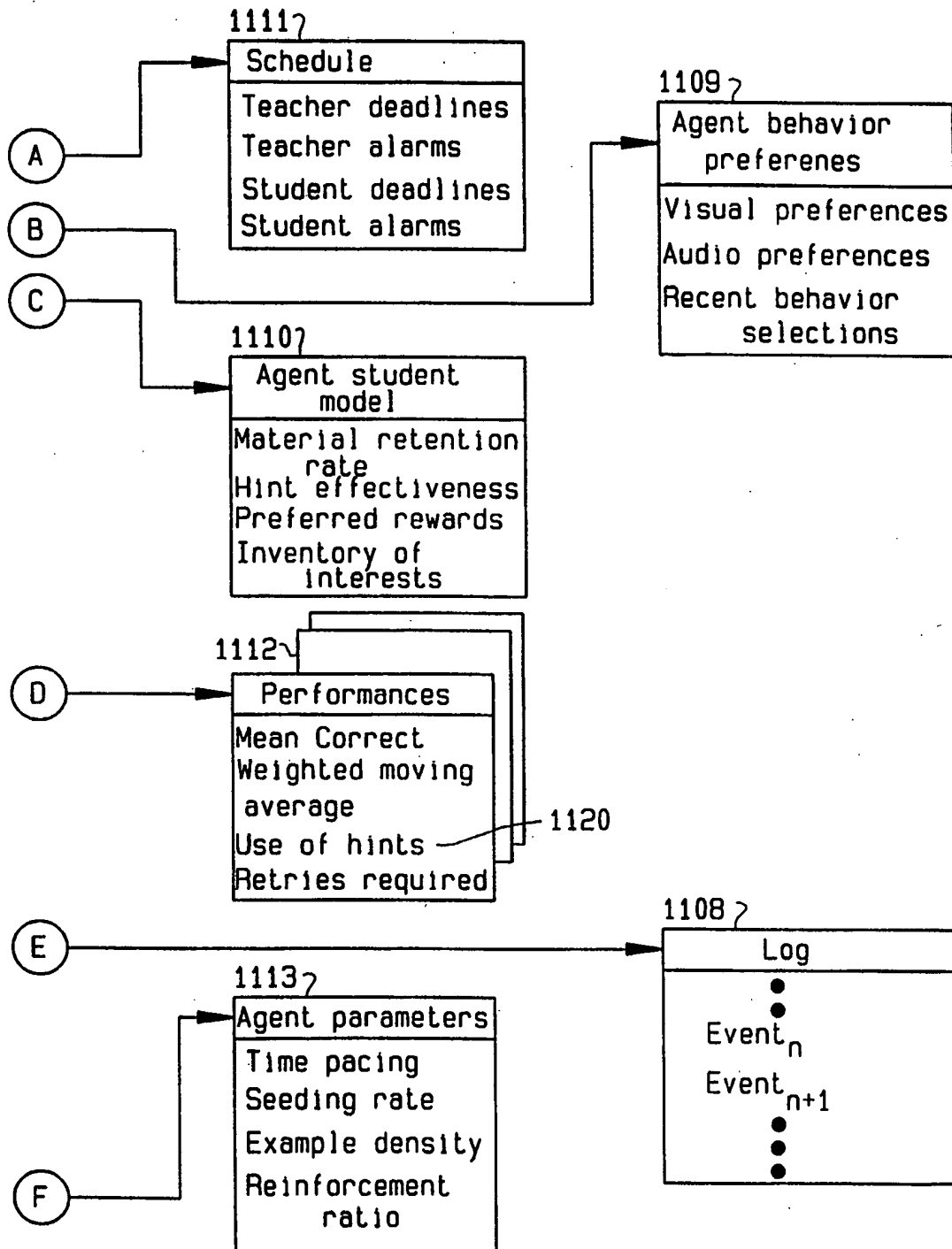


FIG. 10B

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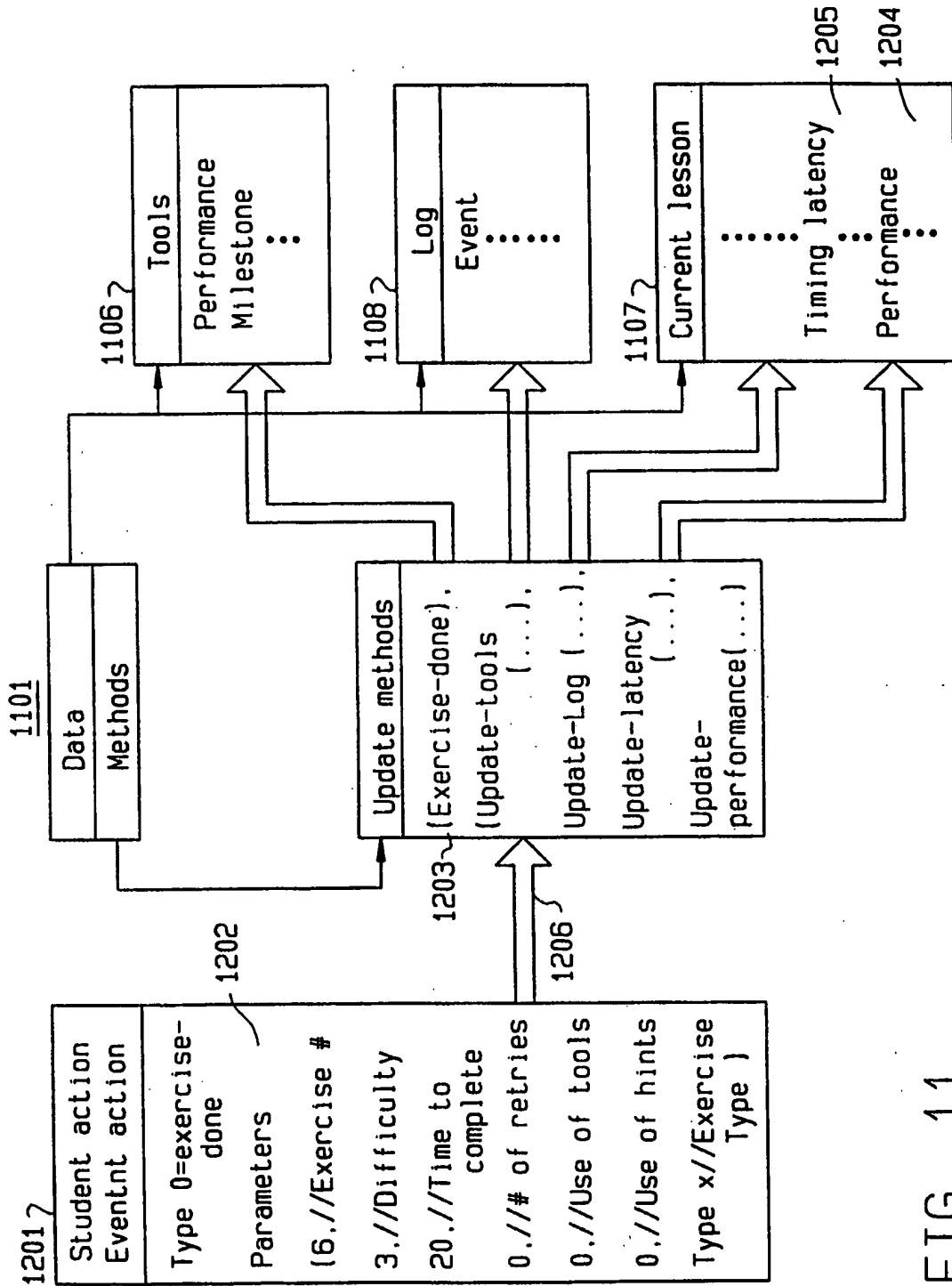


FIG. 11

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METAREQUEST

METARESPONSE

"Where am I"

"You are one quarter through the lesson on adding fractions."

Student clicks  
on "More" icon

\*MATH UNIT 5, LESSON 6\*

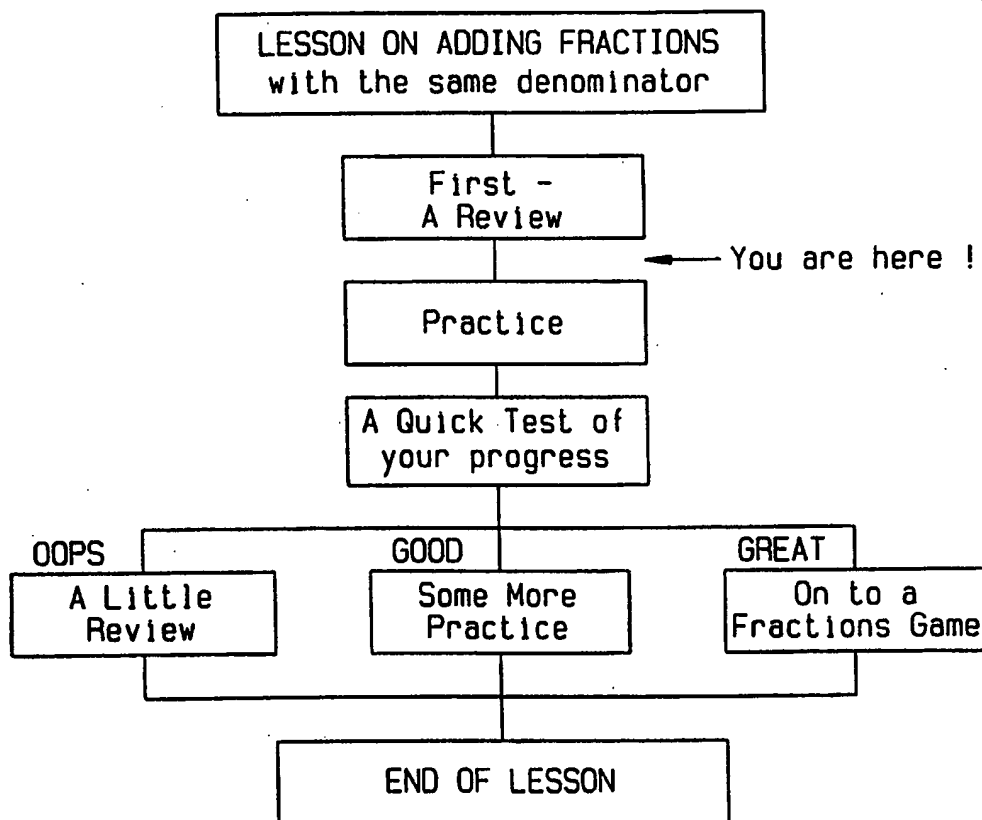


FIG. 12

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/08687

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : G09B 5/12

US CL : 434/350

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 434/350

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category*     | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No.   |
|---------------|--|---|
| X<br>---<br>A | US 5.310.349 A (DANIELS et al) 10 May 1994, col. 3, lines 1-40.                    | 1, 11, 12, 23-27, 30-41, 105-109, 111-116, 118, 127, 133-135<br>-----<br>2-10, 13-22, 28, 29, 40-104, 110, 117, 128-132 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

|   |  |
|---|--|
| * Special categories of cited documents:  | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  |
| "A" document defining the general state of the art which is not considered to be of particular relevance  | "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone   |
| "E" earlier document published on or after the international filing date  | "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "&" document member of the same patent family  |
| "O" document referring to an oral disclosure, use, exhibition or other means  |  |
| "P" document published prior to the international filing date but later than the priority date claimed  |  |

Date of the actual completion of the international search

21 AUGUST 1997

Date of mailing of the international search report

03 SEP 1997

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